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The implications of co-locating marine protected areas around offshore wind farms

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The implications of co-locating marine protected areas around offshore wind farms

By

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Abstract

Offshore wind farm (OWF) construction in the UK is progressing rapidly alongside increasing spatial pressures on marine ecosystems and social and economic activities. A need for increased protection of habitats, species and ecological processes that support environmental and economic benefits is being met by designation of marine protected areas (MPAs). Mitigation and spatial planning solutions are required to enable protection of vital ecological habitats, features and processes and support sustainable economic development. A potential solution is to co-locate OWFs and marine protected areas (MPAs). This study uses a multi-disciplinary approach to examine if evidence on the environmental effects of existing OWFs and associated effects on fishing activity (as an existing resource use) benefits MPA goals. Through a systematic review and meta-analyses of existing data, knowledge of OWF effects on species abundance and economic effects on fishing were identified as key evidence gaps. The ecological evidence need was approached through a case study of ecological effects of North Hoyle OWF, North Wales, UK, using existing pre and post-construction monitoring data, as well as primary baited remote underwater video data, collected 5 years later (8 years post-construction). Results suggested habitat and species recovered to a stable state that showed some community differences to pre-construction conditions. The presence of OWF monopiles is likely to have increased existing heterogeneity of substratum and increased opportunities for scavenging species. Species benefitting and disadvantaged by habitat provided within the OWF reflected meta-analyses trends. Extended baseline monitoring to provide confident identification of natural levels of variation in sediment and fauna was lacking. Analysis of fishing activity and landings before and after OWF construction in three UK case study regions approached effects on resource users. Fishing activity in the three case study areas showed broad scale similarity to national trends. Small-scale activity patterns indicated greater reductions in mobile (towed) fishing gear effort near

to operating OWFs than in static gear activity (using pots or static nets). Semi-structured interviews conducted with fishermen in each region revealed loss of ground and disruption as negative effects from OWFs, in addition to existing pressures. Benefits including habitat creation and species augmentation, as well as reduction of cumulative lost ground, were identified by fishermen from co-location of MPAs and OWFs. Ecological effects of OWFs suggested benefits from habitat creation, species augmentation and potential for protection of sandbank habitats between monopiles. Mitigation requirements were identified to maximise these potential benefits to an MPA network.

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Authors Declaration

At no time during the registration for the degree of Doctor of Philosophy has the author been registered for any other University award.

This research was funded by a Natural Environment Research Council PhD Studentship. The work was carried out in collaboration with Plymouth Marine Laboratory and the Centre of Marine and Coastal Policy Research at Plymouth University.

Several relevant scientific seminars and conferences were attended at which work was often presented. One paper has been published from work from this thesis (Chapter 3) and two further papers are in preparation (from work in Chapters 4, 5 and 6). Knowledge and skills gained during the thesis have been applied to research and industry knowledge exchange projects. A record of my individual contribution to collaborative work is provided as part of this thesis.

Refereed journal publications

Ashley, M.C., Mangi S.C., Rodwell L.D. 2014 The potential of offshore wind farms to act as marine protected areas – a systematic review of current evidence. Marine Policy 45. 301-309.

De Groot, J., Campbell, M., **Ashley, M.,** Rodwell, L., 2014. Investigating the co-existence of fisheries and offshore renewable energy in the UK: Identification of a mitigation agenda for fishing effort displacement. Ocean & Coastal Management, Volume 102, Part A, December 2014, pp 7–18.

Reports

Ashley M.C. *Industry - Research collaboration to identify how better use of existing research and available tools could reduce project risk to streamline consenting within the South West Marine Energy Park*. (NERC Funded Business and Policy Internship - Marine Renewable Energy, with Regen SW and Plymouth Marine Laboratory). Project report prepared for NERC July 2013

Rodwell L., Campbell M., de Groot J., **Ashley M.** 2013. *Fisheries and marine renewable energy interactions*. A summary report on the Fisheries and Renewable Energy Working Group workshop, held York April 2013 for the NERC Marine Renewable Energy Knowledge Exchange programme. Report prepared by The Centre for Marine and Coastal Policy Research, Plymouth UK.

de Groot J., Campbell M., **Ashley M.,** Rodwell L., *Assessing fisheries effort displacement as a result of developing a UK network of MPAs and offshore energy development*. Report to NFFO and Seafish, April 2013

Syvret, M., Fitzgerald, A., **Ashley M.,** Ellis Jones, C., 2013. *Aquaculture in Welsh offshore wind farms: A feasibility study into potential shellfish cultivation in offshore wind farm sites*. A report by Aquafish solutions for Welsh Government, funded by Welsh European Fisheries Fund, (2013).

Rodwell L., Campbell M., de Groot J., **Ashley M.** *Fisheries and marine renewable energy interactions*, A summary report on a scoping workshop, held Orkney May 2012 for the NERC Marine Renewable Energy Knowledge Exchange programme. Report prepared by The Centre for Marine and Coastal Policy Research, Plymouth UK 2012.

Fletcher, S., Smith, N. and **Ashley, M**. (2012) *Co-location in the marine environment.* Report to WWF Cymru.

Research and Industry Knowledge Exchange Programmes

Fisheries and Renewable Energy Interactions Working Group, NERC Marine Renewable Energy Knowledge Exchange Programme (coordinated through The Centre for Marine and Coastal Policy Research, Plymouth University)

Research collaboration to identify how better use of existing research and available tools could reduce project risk to streamline consenting within the South West Marine Energy Park. NERC Funded Business and Policy Internship - Marine Renewable Energy (with Plymouth Marine Laboratory and Regen SW).

Posters and Conference Presentations

The International conference on Environmental Interactions of Marine Renewable Energy Technologies, Orkney Scotland April 2012.
Presentation: *Effects of offshore windfarms on fish and epibenthos: Species specific effects and implications for designation of sites as no take marine protected areas*.

1*st* Marine and Coastal Policy Forum, June 2011, Plymouth, UK. Poster presentation: *Assessing the effects of implementing marine protected areas around offshore wind farms*.

4th Annual Plymouth Marine Science Education Fund Conference, Blue Horizons, Plymouth December 2011. Poster presentation: *Assessing the effects of implementing marine protected areas around offshore wind farms*.

Oral presentations have also been given at the University of Plymouth (Marine Planning course, 2011), Plymouth Marine Laboratory (Science Advisory Committee 2012) and within Research Groups at the University of Plymouth. See Appendix 6 for conference posters.

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Chapter 1. Introduction

1.1 Background

This thesis investigates the environmental, economic and social effects of offshore wind farms (OWFs) in relation to marine protected area (MPA) goals. OWF development is progressing rapidly in Europe and across the world as the principle means of meeting targets for generating energy from renewable resources, to reduce carbon emissions under international agreements (UN 2009). Ecologically driven marine protection in Europe, under the EC Habitats Directive 1992 and EU Marine Strategy Framework Directive 2008, has created an urgent need to understand the effects of these structures on the natural environment and resource users. Global agreements through the 1992 Convention on Biological Diversity extend this requirement around the world (UNEP 2004). This thesis explores these policy drivers and assesses whether protection of marine habitats and renewable energy generation can co-exist. A changing policy and development landscape was present during the course of the thesis. Policy drivers, offshore renewable energy industries, MPA designation and marine planning have developed considerably since 2009/2010. These changes have been adapted to during the course of the work.

Offshore wind farms (OWFs) by their nature are large power plants developed at sea. In the simplest terms the sea provides access to considerable wind resources (ABP mer 2013). Offshore regions also provide space for development that receives less opposition from local communities than developing onshore renewables (Toke 2005, Warren et al. 2005, Devine-Wright 2007). Constructing and operating such large power plants would be almost impossible to achieve without having an effect on the environment they are built within. However, the global scale of climate change and resulting effects mean that renewable energy targets by EU member states and nations globally need to be adopted. These measures provide an essential commitment to a planetary goal to reduce greenhouse gas emission, carbon usage and impede rapid global warming as a result of centuries of damaging human action (United Nations Framework Convention on Climate Change 1992).

1.2 Thesis aim and objectives

The research in this thesis aims to assess the positive and negative effects of OWF development and operation on the marine environment and subsequent economic and social effects on resource users (Figure 1.1). To achieve this aim a systematic review was used to identify the key evidence gaps and a multi-disciplinary study undertaken to approach these evidence gaps. The findings of these studies are reviewed in the context of MPA goals within Europe (OSPAR North East Atlantic region) and the UK (UK Marine Protected Area Network). Ultimately, by identifying and mitigating negative effects on the environment from OWF development and maximising positives, it may be possible to provide renewable energy in a manner that also protects or enhances biodiversity.

1.3 Hypotheses

- Environmental effects

Presence of OWFs will increase fauna diversity and abundance within OWF sites. (null hypothesis – Presence of OWF will not change fauna diversity and abundance within OWF sites)

- Socio-economic effects

Presence of OWFs will lead to increases in catches and fishing effort in proximity to OWF sites. (Null hypothesis – Presence of OWF will not effect catches and fishing effort in proximity to OWF sites)

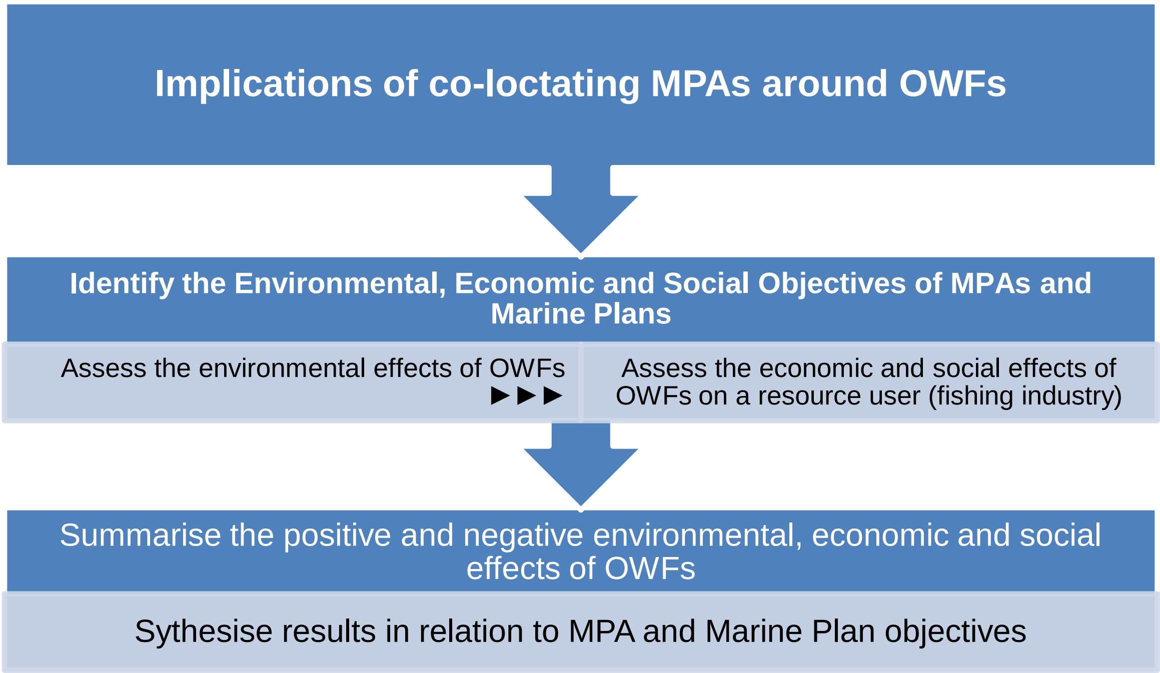


Figure 1.1 Schematic of research pathway to investigate the thesis question on 'What are the implications of co-locating Marine Protected Areas (MPAs) around Offshore Wind Farms (OWFs)?'

The recognition of the effects of increasing carbon dioxide levels on global warming has led to the ideal of providing energy through renewable means, with limited environmental impact (WMO 1986). The understanding that humanity has an effect on the natural environment and that negative effects can and will have direct economic impacts on society was brought to mass attention with forecasted impacts of global warming (Jansson et al. 1994, Sagoff 2012). The prospect pursued by renewable energy development, that harmful fossil fuels can be surpassed, that energy security can become achievable for a growing global population and this can be achieved with limited environmental impact supports the thinking behind the topic of this thesis.

This thesis considers the possibility of further environmental benefits that may enhance natural ecosystems and increase food and economic resources. In a sense this is pursuing the ideals of sustainable practices and the original founding observation of ecological economics; that human economy can be seen as embedded in nature (Jansson et al. 1994, Ropke 2004). The environment essentially provides the source of energy, food and economic resources required by society. The challenge exists to find solutions to providing for all the needs for society in a way that sustains, and ideally benefits the environment.

The work within this thesis concentrates on European developments, with case studies within English and Welsh waters. This is because the EU has committed to cutting carbon emissions to 20% below 1990 levels with 20% of electricity to be generated from renewable sources by 2020. This commitment is one of the headline targets of the Europe 2020 growth strategy and is being implemented through a package of binding legislation. The EU has offered to increase its emissions reduction to 30% by 2020, if other major emitting countries in the developed and developing world commit to undertake their fair share of a global emissions reduction effort (EC 2013). The USA originally pledged 17% below 2005 levels in the Copenhagen Accord (United Nations Framework Convention on Climate Change 1992) and already has 13 % of electricity supplies from renewable sources in 2013 (U.S. Energy Information Administration's 2013). China recently released a statement on reducing its carbon emissions per unit of GDP by 40-45% by 2020 from 2005 levels, and is aiming to increase renewable energy to 15% of its total energy consumption. For 2050, EU leaders have endorsed the objective of reducing Europe's greenhouse gas emissions by 80-95% compared to 1990 levels as part of efforts by developed countries as a group to reduce their emissions by a similar degree (EC 2013).

Addressing potential negative effects and maximising positive effects of OWF development on the environment and natural resources is therefore a global priority. An ever increasing world population presents greater demands on energy resources, food supplies and the natural systems that sustain humanity (Alcamo et al. 2005). Well-informed development of the environmental and socio-economic effects of offshore renewable energy is required at the earliest possible stage in this global development. The question of the effects of co-locating OWFs and MPAs is aimed at developing solutions to ensure multiple benefits to communities and wider society.

Offshore renewable energy already promises to provide energy sources to society with significantly reduced carbon emissions (DECC 2011). This thesis investigates the existing evidence for both benefits and negative impacts arising for the natural environment, and how these affect an existing resource user central to food provision, the fishing industry. The evidence reviewed and provided through original research in the thesis is also aimed to be used within the growing field of marine spatial planning (Ehler and Douvere 2007). Study sites are based in the UK, which has committed to contributing to a well-managed network of MPAs by 2016 (JNCC 2013). MPAs within this network aim not only to protect marine life but also to allow sustainable and legitimate use of our seas to continue (JNCC 2013). Development of this network of MPAs will ensure the UK meets commitments under the Convention on Biological Diversity (CBD 2008), and contribute to measures aimed at achieving '*Good Environmental Status'* across Europe's marine waters by 2020 under the EU Marine Strategy Framework Directive. Renewable Energy development in the UK is similarly driven by legal commitments within the 2009 Renewable Energy Directive to supply 15% of the UKs energy demand from renewable sources by 2020.

Across Europe and coasts around the world, the demands from human activity on the spatial use of the sea are increasing. The need for a balanced plan for use and management of coastal seas has become unavoidable, since the spatial pressures on existing economic uses have increased, as freely accessible sea space has greatly reduced (Ehler and Douvere 2007). Commitments to renewable energy targets and marine conservation targets in particular have increased these pressures in European seas (Ehler and Douvere 2007). The research in this thesis will inform decisions on marine planning requirements, as well as identifying specific positive and negative environmental, economic and social effects in relation to UK MPA network goals.

1.3 Research methodologies

The thesis uses a multi-disciplinary approach to investigate the potential of co-location of OWF and MPAs. The need for this approach was identified through a broad literature review and then a systematic review of available evidence applied to the thesis question. Ecological and socio-economic research techniques were applied to provide a holistic assessment of the suitability of co-location of OWFs and MPAs. As discussed this approach aims to provide evidence to support marine planning and MPA designation decisions. The research pathway and thesis structure undertaken in this thesis reflect the need for a multidisciplinary study to address the required evidence needs (Figure 1.2). The schematic of the research pathway is reproduced in each chapter break, to guide the reader through the stages of the thesis (Figure 1.2).

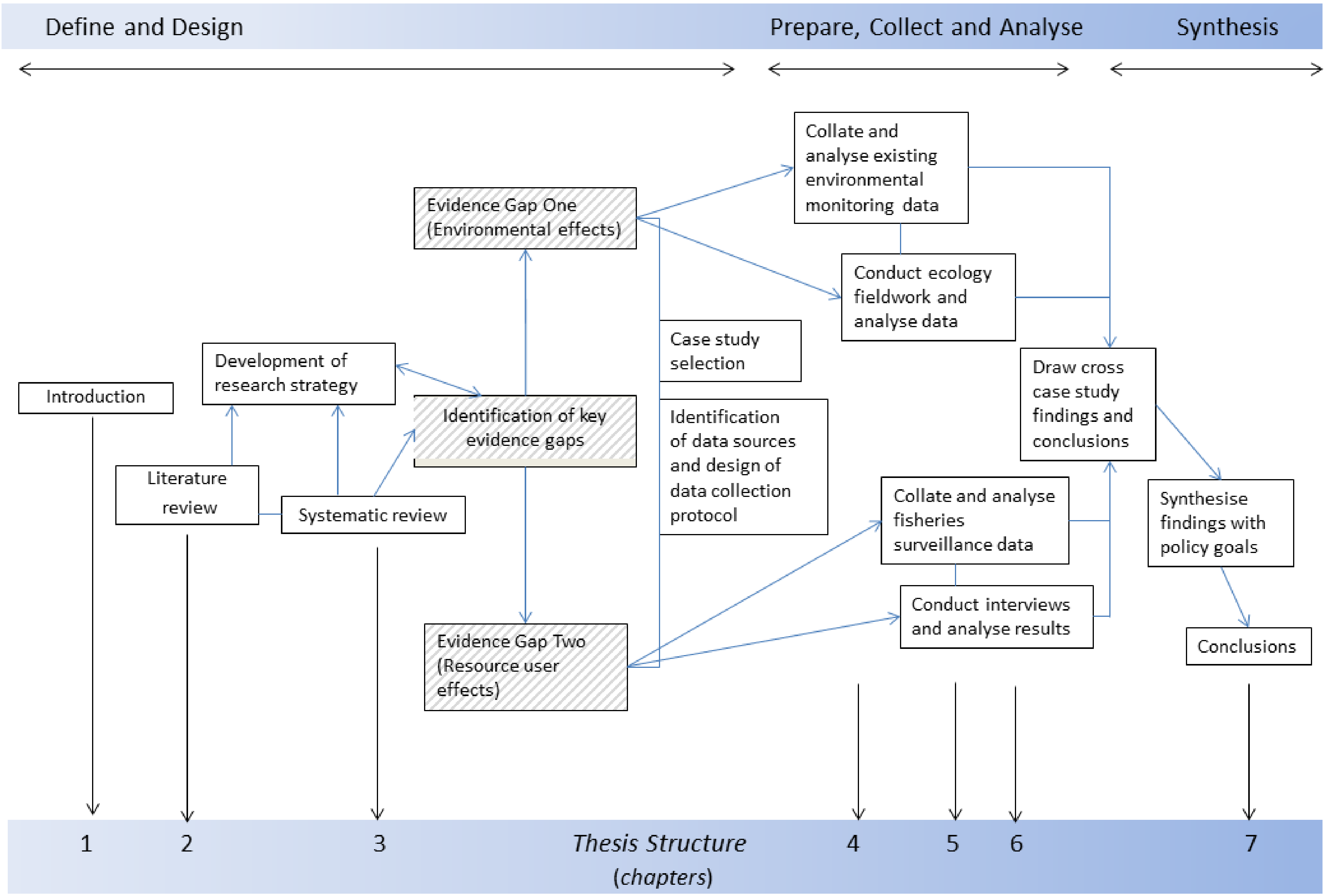


Figure 1.2. Schematic of research pathway undertaken to address thesis question.

1.4 Define and Design

1.4.1 Literature Review and systematic review

The broad literature review examines OWF design and knowledge of effects on ecology and resource users. The state of knowledge on artificial structures and reefs, MPAs and benefits are also reviewed. This initial literature review revealed that there was little evidence on the ecological and socio-economic effects of OWFs. There was limited evidence to assess theoretical predictions that OWF developments can provide a similar role to specifically designed artificial reefs and MPAs. To investigate applied evidence gaps further systematic review and meta-analyses methodologies were applied to the focused question of the effect of OWFs and similar artificial structures on marine fauna and catch and income of local fisheries. This process highlighted priority evidence gaps that required attention. To inform the relationship between OWFs and UK MPA network goals, evidence needs on the effect of OWFs on marine fauna and subsequent effects on fishing activity and catches were identified to be key research priorities.

1.5 Prepare, Collect, Analyse

1.5.1 Evidence Gap One: Effect on marine fauna

To address the first knowledge gap on the effect of OWFs on marine fauna, existing pre and post-construction environmental monitoring data from the UKs first round one OWF, North Hoyle in Liverpool Bay, (Irish Sea, UK) were analysed. As an early test site existing licence requirements only required investigation of large scale impacts (Innogy 2002). Data sets on sediment characteristics, benthic infauna, benthic epifauna and fish had been collected but were only examined individually in the original monitoring reports (RWE npower 2006). In a re-analyses of these data I used multivariate statistical techniques within the software package PRIMER 6 to investigate changes in communities in relation to changes in sediment characteristics inside and at graduating distances outside the OWF. Changes in sediment and benthic infauna were analysed for relationships between the two data sets. Changes in epifauna and fish communities were interpreted in relationship to sediment and infauna data sets.

Environmental monitoring for North Hoyle was only required up to two years post-construction. Effects of seabed disturbance may take five years or more to recover, and management measures such as MPAs are viewed to take five years or more to show beneficial changes (Kaiser et al. 2006, Dinmore et al. 2002, Mangi and Austen 2008). To examine epifauna and fish community changes beyond five years I conducted primary data collection in 2011 on mobile epifauna and fish communities at North Hoyle OWF and the surrounding sea bed using baited remote underwater video camera (BRUV) surveys. This provided data eight years post-construction and five years since the last environmental monitoring survey (2006), to investigate if further changes had occurred. Data on environmental conditions were also collected during these surveys. Community changes were identified post OWF construction that continued eight years post-construction. These changes supported review findings of specific species effects. Habitat changes were observed that also supported trends identified in reviews.

1.5.2 Evidence Gap Two: Effects on resource users

i) *Fishing activity and landings in three OWF development areas*

UK and European OWFs in the Irish Sea and North Sea have been constructed in similar shallow sandbank sediments. The operational UK OWFs in 2011 had little scour protection and rock armouring deposited at turbine bases (DECC 2008). Evidence of species benefits, but also evidence of species community change are identified in the assessment of ecological effects within the thesis. The PhD thesis then addresses whether these species effects are evident in fishing activity and landings. This approaches the second key evidence gap identified in the systematic review; of what the effects of OWF development have been on spatial distribution of fishing activity and catches of fisheries. Fisheries using mobile gears, (trawls, mobile nets and dredges) and fisheries using static gears, (pots, fixed nets and charter angling vessels) were considered separately.

Analyses were conducted to examine if either reduced effort or exploitation of grounds had occurred near to operational OWFs for either gear type category. Analysis of landings data were also carried out to investigate if specific species landings had been affected. Analyses utilised three fishing activity data resources, aerial surveillance (all vessel types), vessel monitoring system (VMS) data (present on over 15m vessels only) and fishermen's activity maps recorded in face to face interviews (all vessel types in local fleets). Data were analysed for the Liverpool Bay region containing North Hoyle also for two further UK OWF development regions. These were the Greater Wash region (North Norfolk and Lincolnshire, UK) and the Greater Thames region (Kent and Essex, UK). Greater reduction in activity near to OWF was evident for mobile fishing activity than static, although catches for all species declined between pre and post-construction periods. Fishing activity across the UK showed a declining trend during the last 10 years which was also represented in all study regions containing OWFs.

ii) Recording fishermen's experience and knowledge

Face to face interviews with fishermen provided an opportunity to gain perceptions and experiences of changes in activity, catches and economic and social effects on livelihoods since OWF development began. The interviews also provided the opportunity to record fishermens historical ecological knowledge of each region and local fisheries to interpret changes. Finally the interview process was used to identify if co-location of marine protected areas and OWFs would be of benefit. Interview respondents also provided alternative solutions to balance OWF development, designation of MPA networks and existing fishing activity in each region. It is acknowledged that only one sector is represented in interviews, OWF developers and conservation managers would have provided further insight into the potential of co-location of OWFs and MPAs.

Interviews reflected the patterns in spatial activity data: mobile gear fishermen experienced the greatest change in activity and resulting pressure on their business. The interviews also revealed how existing activities in each region affected the pressure OWF development placed on fishing activity. This highlighted the importance of taking into account regional differences in fishing practices, existing marine activities and resulting pressures following OWF development when considering planning solutions. Co-location of OWFs and MPAs was supported by a number of mobile and static gear fishermen. Fishermen using static gears perceived the possibility of increased stocks and avoiding conflict with mobile fishing activity. Fishermen using mobile gears that supported co-location perceived that it would be beneficial if it meant MPAs would avoid valuable fishing grounds outside OWF footprints. Fishermen perceived benefits to shellfish species such as crab and lobster from OWFs and reef associated fish if scour protection was utilised. In 2011 fishermen had experienced few noticeable benefits to catches since OWF construction.

1.6 Synthesis

1.6.1 Applying findings to marine planning and MPA designation

The study identified opportunities for OWF developments to maximise the potential for habitat creation alongside the benefit of reducing scour and possible long term sediment disturbance. Such activity may also improve mitigation for resource users. If co-located within MPAs, OWFs provide potential for enhancing populations of certain reef or hard substratum associated species. As OWFs are primarily constructed within soft sediment habitats the trade-off between habitat lost and habitat gained needs to be considered.

The specific goals of the MPA, or regional MPA network under consideration are obviously highly relevant to co-location decisions. The final synthesis and conclusions chapter addresses the conservation objectives of current MCZs and Special Areas of Conservation (SACs) that incorporate OWF co-location zones. The findings of the thesis are reviewed in relation to the 'recover habitat' and 'maintain habitat' conservation objectives of these MPAs. The potential for OWFs to benefit MPA networks through the combination of habitat creation and existing infrastructure deterring fishing practices are discussed. Limitations in the data resources available, suggested improvements in study methods and future research needs are also identified.

1.7 Application of Thesis Research to Knowledge Exchange Projects

Obstacles to achieving co-location and best practice for environmental, economic and social benefits, as well as species enhancement were evident from the start of the PhD project. Particular challenging areas were identified in interactions of fishing and renewable energy industries, the presence of conflicting human activities in the marine environment and goals of planning and regulatory bodies. To approach these issues I conducted a number of projects and collaborations alongside the research conducted for the PhD study. Reports were written and workshops conducted for a range of projects that aimed to enable co-location, assess the effects of displaced fishing activity and also practical development of mitigation activities to aid positive benefits from OWF developments.

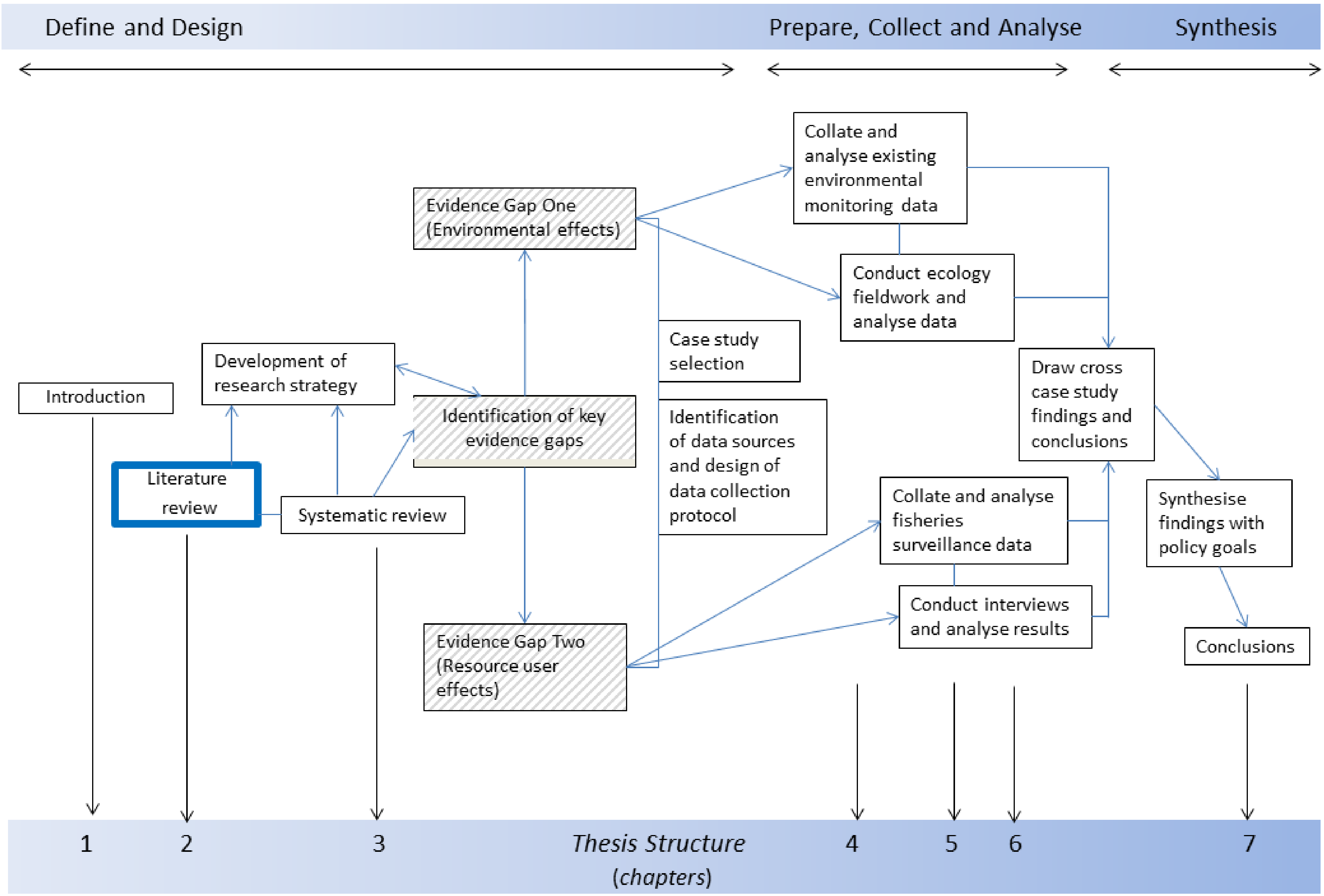
It was evident from the literature reviews and the release of round three OWF lease areas by the Crown Estate in 2009 that there were going to be conflicts with the fishing industry. The effects of displacement of fishing activity were also going to have environmental, economic and social repercussions. I proposed a workshop on the interactions between the fishing industry and renewable energy for the Marine and Coastal Policy Forum held in Plymouth in May 2011 which was taken forward and facilitated by Dr Annie Linley (NERC). There was a large amount of interest in the workshop and this led to the possibility of a full series of national workshops through the NERC marine renewable energy knowledge exchange programme (MREKE). The NERC MREKE funded Fishing and Renewable Energy working group was created through the Centre for Marine and Coastal Policy Research at University of Plymouth, coordinated by Dr Lynda Rodwell, Maria Campbell, Jiska de Groot and myself. Mitigation needs and practical means to improve the communication and consultation process between renewable energy industries and fisheries were identified in workshops in Orkney, Scotland and York, England. These workshop outcomes are discussed in the final chapter of the PhD.

1.7.1 Identifying future research needs

Working on this thesis required keeping track of both policy and industry developments in a constantly moving landscape. Many of the issues identified as priority areas to focus research activities were of relevance to industry concerns as well as planning and policy developments (in relation to marine planning and consent for marine renewable energy developments). This led to a number of opportunities to work on national level knowledge exchange projects to apply knowledge and experience acquired during the thesis to current industry, regulatory and planning concerns.

1.7.2 Putting experience into practice

I have used the knowledge and experience gained in the PhD to address co-location decision making and policy drivers behind co-location in projects for World Wildlife Fund Cymru and Seafish (supported by the Welsh European Fisheries Fund). I also conducted a three month part time NERC marine renewable energy internship to identify priority environmental and socio-economic research questions with the renewables industry and related regulators and planners. The internship aimed to ensure information on current research methods and tools and the research groups applying them were known to the industry. This work intended to address issues identified during the thesis such as limited data availability, lack of uniform survey design in environmental monitoring and lack of practical studies of environmental and socio-economic mitigation. The project also aimed to aid communication between research and industry.


Define and Design
Prepare, Collect and Analyse
Synthesis
Collate and analyse existing environmental monitoring data
Evidence Gap One (Environmental effects)
Conduct ecology fieldwork and analyse data
Case study selection
Development of research strategy
Introduction
Identification of key evidence gaps
Identification of data sources and design of data collection protocol
Draw cross case study findings and conclusions
Literature review
Systematic review
Collate and analyse fisheries surveillance data
Synthesise findings with policy goals
Conduct interviews and analyse results
Evidence Gap Two (Resource user effects)
Conclusions
1
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Thesis Structure (chapters)
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7

Chapter 2. Literature review

The effects of implementing marine protected areas around offshore wind farms.

2.1 Introduction

There is currently a rapid expansion of offshore wind farm (OWF) development in order to help the UK meet its target of 15% of energy generation from renewable sources by 2020 (The Renewable Energy Directive 2009, Crown Estates 2010, DECC 2010, DECC 2010a, HM Government 2011). Similar targets are shared across EU member states under the Renewable Energy Directive 2009 in order to meet targets to reduce greenhouse gas emission, carbon usage and impede rapid global warming (Figure 2.1).

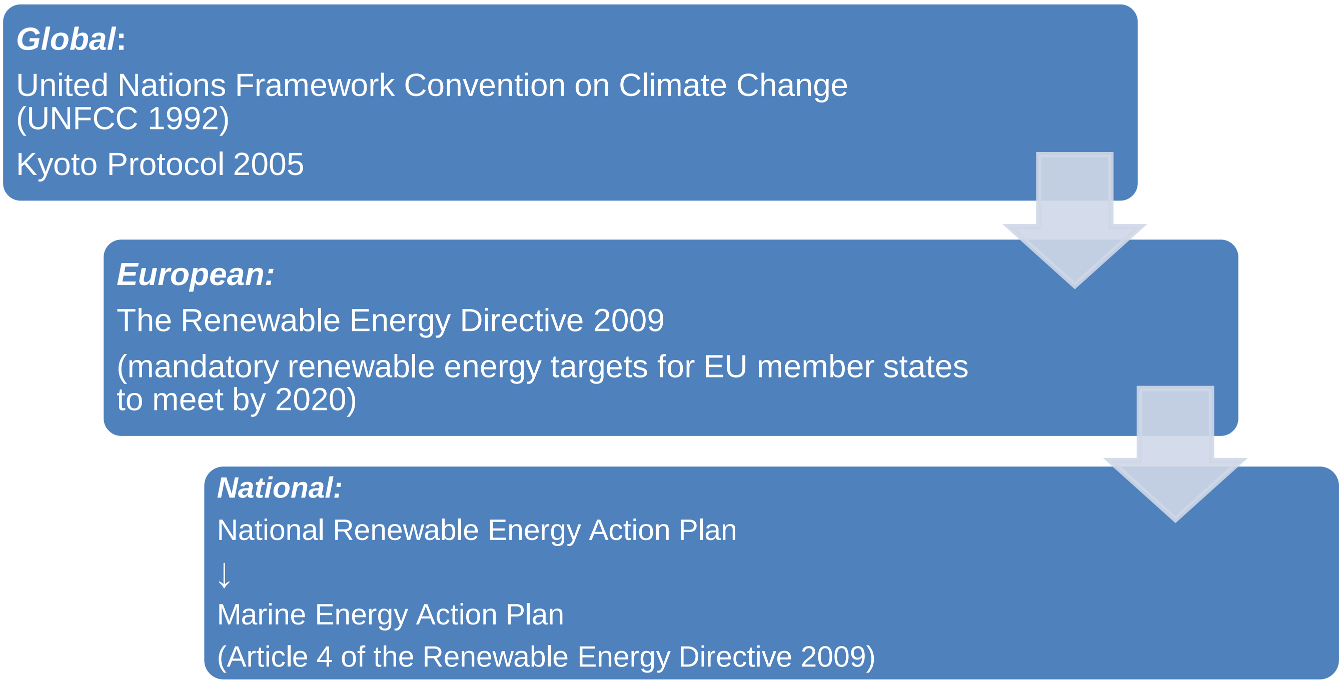


Figure 2.1 Global, European and national level agreements and policy leading to OWF development in English and Welsh seas.

OWFs are being developed globally to achieve renewable energy goals; currently the UK has taken the greatest steps in developing OWFs to reach its target (Figure 2.2).

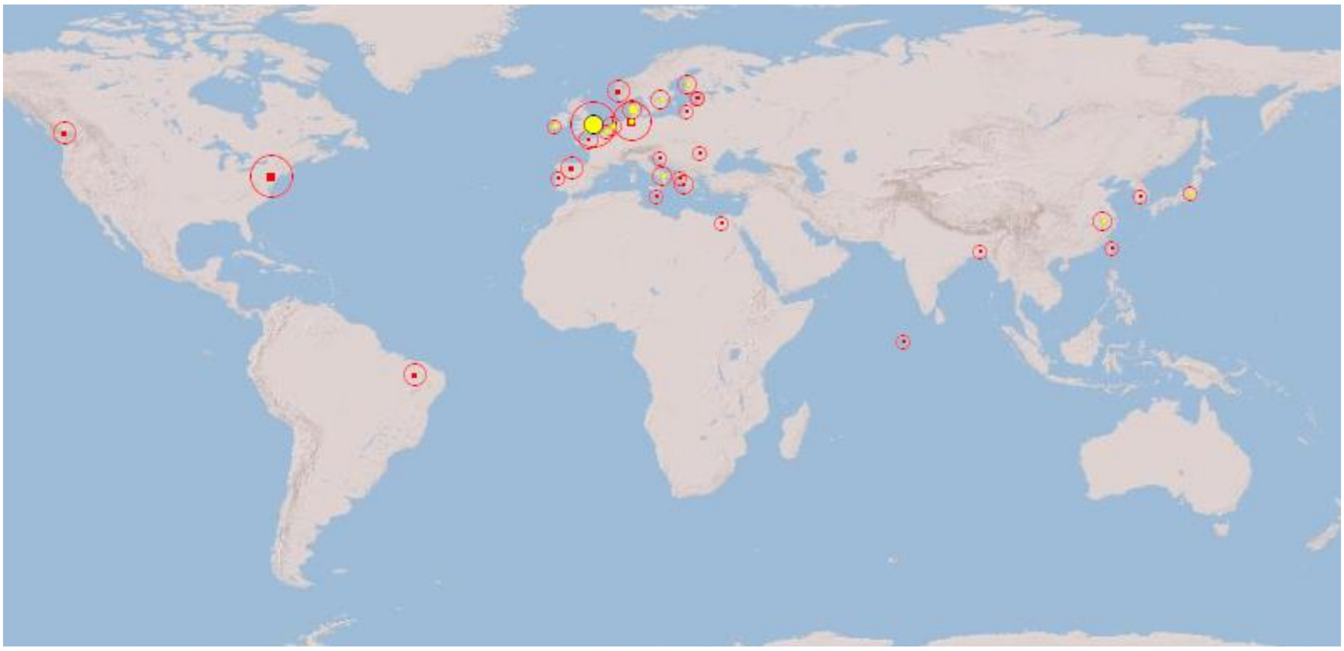


Figure 2.2 Global map of planned OWF sites (dark red circles) and operating OWFs (yellow circles) for each country in 2013, circle size is relevant to MW value; larger circles correspond to greater MW output.

By 2010 when fieldwork for this thesis began, twelve small scale OWFs occupied 144km² of seabed within the UKs territorial waters producing 1.4GW, 1% of the country's electricity requirements (UK round one) (Table 2.1). Between 2010 and 2013 during the course of this thesis 10 further, larger OWFs have been constructed within twelve nautical miles of the coast providing a further 6.7GW (5% of electricity requirements) (UK round two) (Table 2.1). The data available on the 4C Offshore online wind farm database (4C Offshore 2010, 2013) show these projects will have raised the total seabed footprint of OWFs across Europe to approximately 417km^2. The government plan for 2020 is to have constructed larger wind farms on or beyond the 12 nautical mile limit (UK round three) providing 25.5GW and bringing the total for the country's electricity generation through offshore wind power to 25% (Crown Estates 2010, DECC 2010.DECC 2010a). By 2020 the estimated seabed footprint within UK territorial waters occupied by OWF sites (leased areas) will be approximately 28007km^2. If seabed areas leased for OWF developments across Europe are considered the footprint of seabed areas leased to OWFs will occupy approximately 28384km^2 of European seas (Table 2.1) (4C Offshore database 2010, 2013). Current plans for larger sites use only a portion of the leased area. Footprints of leased areas can therefore be further divided into the footprints of the sites occupying leased areas. The individual turbine bases may occupy up to 8 metres in diameter, depending on scour protection or base design. Turbine base and scour protection areas, multiplied by the number of turbines in each OWF, provides a further interpretation of the footprint (Table 2.1).

Table 2.1 Development of OWFs in European seas between 1991 and 2020, including the total area of seabed (km^2) leased for OWF sites and total number of turbines deployed (data compiled from the 4C Offshore database 2013).

	1991	2000	2002	2003	2007	2009	2010	2011	2012	2015	2020
Turbines deployed	11	50	130	160	496	751	851	941	1260	2268	
Area Km^2	2	8	29	39	139	227	262	296	417	1122	28384

The spatial extent of the OWF footprint (10 km^2 for current round one sites to over 1000km^2 for proposed round three sites), combined with increases in hard substrata within offshore areas will inevitably lead to alterations of habitats and communities at a variety of spatial scales (Jenson et al. 2000; Peterson and Malm 2006). There are also inevitable consequences for economic activities utilising the marine environment from aggregates to shipping and fisheries sectors (Costanza et al. 1997; Gill 2005; Beaumont et al. 2007; Punt et al. 2009; Inger et al. 2009).

Extensive reviews conducted by Hiscock et al. (2002), Gill (2005), Linley et al. (2007, 2008), Inger et al. (2009) and Wilson et al. (2010) have highlighted the potential environmental advantages and disadvantages from construction, operation and decommissioning of marine renewables and OWFs in particular. With construction of OWFs progressing rapidly in the UK there appears a pressing need to assess these benefits and disadvantages to a greater extent. Linley et al. (2007), Inger et al. (2009) and Wilson et al. (2010) raise the issue that these structures have the capacity to act as *de facto* MPAs providing artificial reefs, fish aggregating devices, and exclusion zones to destructive anthropogenic activities. However, empirical evidence to examine these possibilities is sparse. Therefore, there is a need to understand the effects of these structures on the natural environment and the interaction with resource users such as fisheries. This research is of further relevance considering the pending implementation of nationwide marine conservation zones.

2.2 Review objective

This chapter reviews current knowledge on the premise that the creation of habitat and the reduction of fishing effort within OWFs can increase biodiversity and the abundance of fish and crustacean populations. The objective is to assess the evidence on the positive and negative effects of OWF sites on biodiversity, fish populations and associated fisheries to meet the needs of an effective MPA. MPAs are required through binding agreements to protect biological diversity and ensure good environmental status of European seas by 2020 (Figure 2.3). OSPAR, the facilitators of the EU Marine Strategy Framework Directive for the North East Atlantic define MPA goals within the OSPAR definition of an MPA;

> *"an area within the [OSPAR] maritime area for which protective, conservation, restorative or precautionary measures, consistent with international law have been instituted for the* ***purpose of protecting and conserving species, habitats, ecosystems or ecological processes of the marine environment****" (OSPAR 2003 Annex 9 A-4.44a)*

The UK has commitments under these international agreements to set up an ecologically coherent network of MPAs. This network will incorporate several types of MPAs giving different levels of protection. These include; Special Areas of Conservation (SACs), Special Protection Areas (SPAs), Sites of Special Scientific Interest (SSSIs) / Areas of Special Scientific Interest (ASSIs), Ramsar sites, Marine Nature Reserves (MNRs) and Marine Conservation Zones (MCZs) (JNCC 2013a).

Within the UK, devolved administrations will have additional legislation in place through the Marine and Coastal Access act (MCAA) 2009 to regulate their territorial waters. Section 116 of the MCAA provides the power for the Ministers (Welsh, Scottish, and the Secretary of State) to designate areas as marine conservation zones (MCZ) by means of local orders. In English inshore and offshore waters final designation is made by the Secretary of State. The Secretary of State also makes the final designation for MCZs in Northern Irish and Welsh offshore waters. MCZs in offshore waters in Scotland will be designated by Scottish ministers. In inshore waters in Wales MCZs will be designated by Welsh ministers. The Northern Ireland marine bill allows for the designation of areas as marine Conservation zones (MCZs) in inshore regions with the agreement of the Secretary of State. Under the Bill, designation may be carried out for conservation of species, but must take fully into account economic and social consequences of designation (DOE, 2011). The goals of MPA networks in England are stated by JNCC to protect marine life while taking into account social and economic consequences:

> "*MPAs will protect marine life while allowing sustainable and legitimate use of seas to continue* (JNCC 2013)

All MPA sites are founded on ecological criteria; however, the ecological and socio-economic effects of fishing effort displacement are also relevant. Under the MCAA the designation of marine nature reserves within a marine conservation zone network requires assessment of social and economic impacts from designation of sites, as well as assessment of biological criteria. The drive for establishment of an MPA network in the UK will aid European seas to reach 'good environmental status' by 2020 (Figure 2.3). For the purpose of this review the socio-economic effects of OWFs on fishing activity are also considered in view of mitigation measures to sustain fishing activity within the region. The ecological implications of fishing effort displacement on regional fish stocks and habitats are also relevant.

Figure 2.3 Global, European and national level biodiversity agreements and policies, leading to designation of marine protected areas in English and Welsh seas to achieve '*good environmental status by 2020*.'

Through this review existing information is synthesised on the effect of introducing artificial structures and limiting fishing activities on habitats and fish populations. The use of artificial structures for biodiversity conservation and maintaining sustainable fisheries are also considered. Following an introduction to OWF design and construction the review is divided into two broad themes.

1. The first addresses biological community reactions to introducing man-made structures offshore and designating MPAs.
2. The second considers the social and economic effect of OWF development and MPA co-location on fisheries as a primary resource user. (When managed as a sustainable and legitimate use of the sea).

As globally OWF construction is in early development this review is supplemented from studies of structurally similar offshore structures including offshore oil platforms and areas closed to fisheries over similar scales.

2.3 OWFs, Design and Construction.

Current OWF technology relies significantly on adapting terrestrial wind turbine design to the marine environment. Operational OWF sites are currently located inshore, within water depths not exceeding 30 m. Therefore, the monopole design dominates due to the existence of tested pile driving techniques and available sand, gravel and mud banks. However these construction methods are time consuming, costly and impractical in offshore environments, especially due to the need for calm weather conditions. The excess environmental loading on turbines due to combined wind and wave forces also limits the efficacy of monopile techniques in deeper locations (Byrne and Houlsby 2003). Engineering is further complicated due to loose mobile sand banks, glacial till and soft clay sea beds (Byrne and Houlsby 2003). As sites have been leased further offshore (for example the UKs round three sites which are up to 12 nautical miles offshore and in water depths reaching 60 m) engineering requirements have called for more robust structures with gravity base and tripod designs currently favoured. Further adaptations to open up deeper, increasingly wind rich resources have required engineers to develop concept designs for floating turbines. Although anchored to the sea bed, floating turbines reduce the engineering complications of pile-driving and reduce challenging high risk at sea construction work. As such floating turbines can be located in hundreds of metres of water (Statoil 2012). Current monopole, gravity base, and tripod base designs, as well as concept floating turbines are displayed in Figure 2.4.

a) b) c) d)

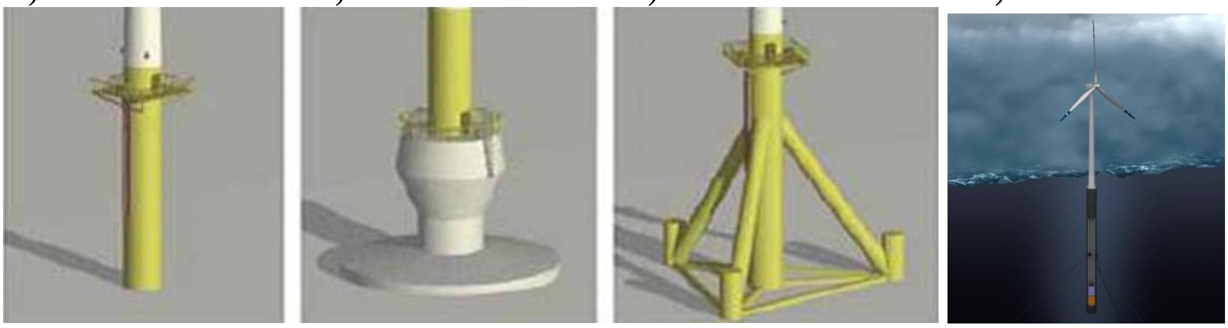


Figure 2.4. a) Monopile, b) Gravity base, c) tripod and d) experimental floating turbine designs (Linley et al 2007, Statoil 2012).

i) Monopile design

Monopile designs consist of a cylindrical steel structure, typically between 2.5 and 4m in diameter that is driven 10m to 50m deep into the sea bed (Harland and Wolff 2001, National Wind Power and RWE, 2002). Ideally sea bed materials allow a hole to be drilled, within which the turbine can be secured using grout and cement. Depending on the extent of scour occurring at each location, scour protection consisting of rock or boulder materials may be scattered on the sea bed in an approximately 10m diameter around the base (Metoc 2000, Hiscock et al. 2002) (Figure 2.4 a).

ii) Gravity base design.

Established in the oil and gas industry the gravity base design utilises a concrete base approximately 15 to 25m in diameter and 15 to 20m high, and up to 2000 tonne that the turbine is attached to. Depending on the sea bed material surface preparation currently requires removal of silt and laying a horizontal shingle layer (Harland and Wolff 2001, Hiscock et al. 2002), however designs are currently evolving that do not necessitate surface preparation (Stanich 2010). Developing concepts in gravity base deployment allow individual bases to be towed to OWF sites and avoid the negative impacts of drilling, pile driving and hazardous working conditions aboard offshore vessels (Harland and Wolff 2001, Stanich 2010) (Figure 2.4 b).

iii) Tripod or Lattice base design.

In the tripod or lattice base design the turbine is attached to a platform that itself is then attached to the sea bed by multiple upright structures. The whole structure has an approximate diameter of 15m to 25m and stands 15m to 20m high. Each individual supporting leg structure is constructed of steel and is approximately 1m to 1.5m in diameter and 15m to 20m high. These supporting legs are secured to the sea bed using similar pile driving techniques to those utilised for monopole structures, with drilling to depths of 10m to 20m (Harland and Wolff 2001). The high cost of manufacture limits the use of this design in all but the deepest sites, where excess loading and stress on the turbine excludes the use of monopole and gravity foundations (Harland and Wolff 2001) (Figure 2.4 c).

iv) Floating turbines.

Current concepts for floating turbines include three main structures, the first uses a large floating platform or ‘barge’ that a turbine is mounted on. These structures are required to be sufficiently large enough to support the turbine and limit pitch and roll through a weighted water plane area. Barge designs use mooring lines anchored to the sea bed to keep the platform in position.

The second design referred to as ‘ballast stabilised’ incorporates a large cylindrical underwater ballast tank that is weighted to create a righting moment and high inertial resistance to pitch and roll. This structure is held in mid water through mooring lines with the turbine extending up from the moored weighted ballast tank. The third structure ‘mooring leg stabilised’ uses three or more mooring lines running from a floating tripod base that is held in mid water, the tension on the mooring lines therefore maintaining stability (Butterfield et al. 2005). One operational test turbine is in the water, the ‘Hywind’ constructed and operated by

Statoil Hydro. Hywind applies the ballast stabilised method to support a 100m high turbine with 45m blades, the turbine and ballast tank extends 100m deep that has supplied energy to Norway's grid since 2009 (Statoil 2012). The success of this design has led to plans for a larger test park off the coast of Scotland. If they continue to be successful these designs potentially eliminate the depth limitations of designs relying on direct sea bed construction (Figure 2.4 d).

Theme One: Ecological Effects

2.4 Effects of OWFs on marine fauna and communities

Engineers currently rely on the monopile design, with gravity base foundations planned for some of the future sites. This review will firstly focus on the habitat implications of these structures (Appendix 1). Later sections will consider the additional implications of the reduction of fishing effort and the implications of displacement of fishing effort. Although linked to the effects of turbine design on biodiversity, effects on fishing activity are also likely to be influenced by the extent of the area within the OWF footprint.

Hiscock (2002) accessed available databases (Marine Nature Conservation Review database), and results from a variety of studies of benthic and epibiotic communities associated with rocky substrata and artificial structures such as jetties and oil platforms. Zonation characteristics and likely communities which would appear on turbine towers over time were predicted. From this review Hiscock (2002) identified two possible options, 1) communities dominated by mussels and predatory starfish or, 2) dominance by communities with high abundance of plumose anemones, hydroids and solitary sea squirts. In the first community type scavengers such as starfish, plaice and flounder could be expected feeding on detached live mussels (Hiscock, 2002; Linley et al. 2007).

Empirical research into faunal communities developing on turbine structures and within OWF footprints was limited in the review and planning stages of the thesis. Only two peer reviewed studies addressing fauna communities on OWF structures were published. Both of these addressed monopile foundations at small scale OWF test sites, Yttre Stengrund and Utgrunden in the southern Baltic Sea (South-eastern Sweden). The species assemblages recorded in association with these OWF structures showed significant differences two to three years after construction in comparison to assemblages recorded at control sites in the surrounding habitat (Wilhelmsson et al. 2006; Wilhelmsson and Malm 2008). Assemblages appeared to closely represent the first predicted (filter feeder dominated) community proposed by Hiscock (2002).

Fouling assemblages occurring on OWF turbines are reported to have higher biomasses of sessile, suspension feeding organisms (the mussels *Mytilus trossulus*, *Mytilus edulis* and the barnacle *Balanus improvisus)* and a reduction in algae species in comparison with adjacent habitat (Wilhelmsson et al. 2006; Wilhelmsson and Malm 2008). Motile invertebrates also show a significant difference in assemblage structure between turbines and surrounding habitat, with higher biomass of amphipod (*Gammarus spp*.) and lower biomass of algal associated gastropods and sand dwelling bivalves (*Mya arenaria, Macoma baltica*). The monopile habitat studied also provided twice the crustacean biomass compared to that from the surrounding habitat (Wilhelmsson and Malm 2008).

Cascade effects as a result of changes in available habitat and food resources may affect fish communities (Pace et al. 1999). As the principal food source for many fish species, the higher abundance of colonising amphipods and crustaceans may increase occurrence of predators (Reubens et al. 2010; Wilson et al. 2010).

Similarly the significant increase in biomass of mussel species such as *Mytilus edulis* and occurrence of colonising amphipod species, combined with the reduction in algal species provides a large shift in available food resources for higher trophic level species in the region. The habitat alteration caused by the construction of OWF turbines therefore presents the potential to initiate key trophic level interactions with potential trophic cascade effects (Pace et al. 1999; Wilson et al. 2010).

Only observational evidence was available for this possibility at the start of the thesis with large shoals of juvenile whiting, *Merlangius merlangus* (a UK biodiversity action plan species) reported feeding on the amphipod *Jassa falacta* at turbines within North Hoyle OWF (UK) (Bunker 2004; RWE npower 2006). Observations have also been made of juvenile cod *Gadus morhua* and plaice *Pleuronectes platessa* near the sea bed adjacent to the turbines (Bunker 2004; RWE npower 2006). During the course of the thesis further evidence has come to light including the presence of the Gadoid, pouting (*Trisoptus luscus*) occurring in high abundance at turbines in the Belgium North Sea (Reubens et al. 2010, 2013). Stomach content analyses showed the fish were feeding on prey occurring on the turbines (Reubens et al. 2010, 2013).

2.5 Offshore wind farms and artificial reef effect

Detailed surveys of demersal fish occurring at Yttre Stengrund and Utgrunden OWFs revealed the structures may function as combined artificial reefs and fish aggregation devices for small demersal fish (Wilhelmsson et al. 2006). Large aggregations of gobies, *Gobiusculus flavescens* and *Pomatoschistus minutus* occurred at the turbine structures (Wilhelmsson et al. 2006). The study, however, focused on abundance and therefore observations of behavioural association such as feeding were not recorded**.** Association of demersal fish species with vertical structures mimicking offshore OWF has also been displayed by *G.flavescens* and goldsinney wrasse (*Ctenolabrus rupestris*) at an experimental test site on the Swedish west coast (Andersson et al. 2009). Andersson et al. (2009) compared faunal associations occurring in relation to steel and concrete structures (designed to represent turbine bases) and found that construction material had little effect on fish assemblages. Significant differences in fouling assemblages were, however, identified between each material. This suggests that these fish species were not just exploiting food resources but the structures themselves. Taken together with the observations of juvenile whiting feeding on amphipods living on turbine surfaces at North Hoyle OWF monopiles, there appears considerable potential for OWFs to enhance abundance and diversity of fish species due to multiple behavioural responses. The structures may provide a combination of benefits such as, providing food resources and offering increased opportunities for shelter. Current studies relate increased abundance of mobile fish species to the presence of increased production at OWF pilings (Wilhelmsson et al. 2006; Reubens et al. 2013). Stomach content analyses of fish feeding at OWF pilings identified prey species that occur on pilings, and sampled fish were in good condition (as a result of feeding on turbine pilings) (Reubens et al. 2013).

OWF turbine pilings have been shown to aid abundance of reef associated species. As well as the pouting schools shown feeding by Reubens et al. 2010, 2013), environmental monitoring at Horns Rev I OWF in Denmark has shown increased abundance of reef associated fish close to monopiles 7 years post-construction (Leonhard et al. 2011). Gill net catches were also greater closer to turbines at Lillgrund OWF in Sweden (Bergstrom et al. 2012). Experimental manipulation, adding complexity through a series of holes to 11 of 21 concrete wave energy buoy foundations at a test site in Lysekil, Sweden further increased species abundance (Langhamer and Wilhelmsson 2009). Increasing the habitat complexity and shelter opportunities revealed species specific results with a dramatic increase in brown crab (*Cancer pagarus*) (Langhamer and Wilhelmsson 2009). In comparisons between all foundations and bare sand control sites, species diversity and abundance were greater in association with the complex foundations (Langhamer and Wilhelmsson 2009).

The addition of simple methods of increasing habitat complexity provides an opportunity to increase the application of wave, and comparable wind energy artificial structures to enhance the abundance and diversity of species that sustain economic activities. Wilson and Elliott (2009) provide achievable means for OWF developers to provide similar benefits utilising available materials and techniques. The use of large rock sour protection or specifically designed artificial reef material is proposed to be of greater benefit than materials such as gravel, which typically support less diverse communities (Wilson and Elliott 2009).

Early OWF fauna community studies also suggest that the design and position in the water column of a structure has a greater influence on community development than the time the structure was deployed, or its size (Wilhelmsson and Malm 2008). The initial communities developing after two to three years of turbine presence in inshore habitats closely reflect the pier piling communities recorded along the Californian coast by Davis et al. (1982). This suggests that even over longer timescales a large scale community (given the surface area provided by pilings) within an OWF footprint will continue to be dominated by filter feeders, especially mussels (*Mytilus spp*.). The Wilhelmsson and Malm (2008) study, with filter feeding communities dominating after two to three years of OWF construction suggests these habitats do not provide surrogates for naturally occurring substrata in the area. Instead they provide habitats comparable to those found during fouling studies of similar man-made structures in the Baltic region such as bridge pilings (Qvarfordt et al. 2006) and therefore, the mussel dominated communities predicted by Hiscock (2002). If community structure continues to mimic that seen at pier and bridge pilings, which have been present for considerable time periods, the communities colonising turbines are unlikely to develop further, even with increasing time of submergence (Wilhelmsson and Malm 2008). Over time the communities adjacent to OWF pilings are likely to be affected (Wilhelmsson and Malm 2008).

Mussel mounds occur as a result of the persistent colonisation of mussels on the submerged artificial structures of oil and gas platforms along the Californian coast (Love et al 1994, 1999). Mussel mounds and adjacent platform structures have been shown to develop significantly different communities to surrounding natural habitats (Love et al. 1994). As with the developing evidence from OWF sites these mussel mound reefs are utilised by a diverse assemblage of fish species, dominated by rockfish species and occasional high densities of ling cod, both of which are of commercial importance (Love et al. 1999). No specific community could be attributed to the mussel mounds alone, with greater similarity of fish assemblages occurring between mussel mounds and the platform structure above, than across individual mussel mounds as a whole (Love et al. 1999). As offshore platforms in this region have been operating since 1958, the similar functional type communities developing in relation to OWFs would appear to be unlikely to change significantly with time submerged. Future OWF developments are also likely to produce similar colonisation sequences.

Oil and gas rig fish assemblages were location specific not habitat specific (i.e. rig structure or mussel mound) specific. This suggests that fish assemblages occurring at artificial structures are likely to be opportunistic, depending upon the fish species occurring in that location, and may be attributable to much wider or more distantly affected environmental conditions (Clynick et al. 2008). In considering OWFs within MPAs it appears important to assess fish population effects on a case by case basis, using comparable survey designs. Results from multiple sites will display broad trends to provide evidence on the fish functional types that will be influenced by the structures. On a regional basis the habitat requirements of locally important species can be assessed in order to comprehend if the habitat provided by OWFs will benefit that region. These results will be applicable to providing evidence to aid achieving regional goals of MPA networks.

2.6 OWFs suitability as MPAs

The increased abundance of food sources for higher trophic level species, in particular fish of commercial importance, are of direct interest to assessing OWFs as MPAs. If the communities that have been recorded within existing OWFs persist over time there are potential benefits to augmenting populations of commercially targeted species (Langhamer and Wilhelmsson 2009; Reubens et al. 2010, 2013). Even if OWF sites maintain non-naturally occurring communities, MPA designation may still attain the goal of protecting and enhancing diversity and abundance of an exploitable commercial resource.

When this study began there was a limited evidence base for fish species abundance and fish communities occurring in relation to OWFs. Existing peer reviewed studies presented results from two smaller (7 turbine and 4 turbine) OWFs in the coastline of one country (Sweden) (Wilhelmsson et al 2006; Anderson et al 2009) (Appendix 1). To provide necessary evidence to support MPA and OWF co-location decisions, site specific studies at a range of OWF sites appeared necessary to develop the required evidence base. It was also identified that communities occurring at case study sites required significant monitoring and continuous assessment. A requirement was also evident for studies to assess similarity of OWF piling communities over time to communities in naturally occurring habitats. Assessment was also required of the influence of the communities developing on turbines on species occurrence and communities at surrounding natural soft substratum and hard substratum habitats (Hiscock et al. 2010; Wilson et al 2010) (Table 2.2).

Given the OSPAR definition that MPAs serve as a means of '*protecting and conserving species, habitats, ecosystems or ecological processes of the marine environment,'* the species, habitat and ecosystems and related processes that are being conserved or promoted within OWFs need to be thoroughly understood. This will aid early identification and mitigation of potential negative impacts. Such an approach would appear vital given the scale and spatial extent of planned sites, covering in excess of 6000km² with up to 2500 turbines in increasingly distant offshore locations, such as Dogger Bank (Crown Estate 2010). If damaging effects on habitats and species were identified this would require the precautionary approach to be adopted. Under this scenario appropriate measures are required to be considered by decision-makers and research targeted at issues to provide reliable scientific data (EC 2000).

2.7 Negative biodiversity effects of offshore wind farms

i) Invasive species

One threat identified by Wilhelmsson and Malm (2008) in addition to the occurrence of non-naturally occurring (filter feeder dominated) communities was the threat of alien invasive species. The intertidal giant chironomid, *Telmatogeton japonicus* naturally occurs in Asia but has been consistently recorded on the hulls of international merchant ships (Brodin and Andersson 2009). The species was reported by Wilhelmsson and Malm (2008) to have been found in the splash zone on several of the OWF turbines at the Utgrunden study site. Although this represented the first record of the species along the Swedish coast further fouling community studies at OWF sites in Denmark reported that this alien species dominated the splash zone on OWF pilings in Denmark (Dong Energy et al. 2006). The species has also been recorded in fouling community studies of vertical structures of offshore buoys in Belgium waters (ICES 2005).

By 2009 all development stages of the species had been identified on OWF pilings at Utgrunden suggesting that its distribution will continue to expand in this region (Brodin and Andersson 2009). *Telmatogeton japonicus* potentially provides a positive effect as a food source for higher trophic level species in the regions it extends its distribution into. However, the potential for invasive species with identified negative effects on local biodiversity, communities and species survival is readily identifiable for regions with existing OWFs and plans for future OWF developments. Other artificial structures in European seas are also colonised by alien, non-naturally occurring species within the first years of submergence (Hiscock et al. 2010). Within the North Sea many identified alien or invasive species are now recorded to be common in intertidal and shallow subtidal habitats, to the extent that they will have inevitable effects on existing species communities in natural habitats (Kerckhof et al. 2007).

ii) *Didenum vexillum* (Japanese sea squirt) colonisation of the Irish Sea

The North Coast of Wales within the North East Irish Sea currently contains three operational OWFs producing 240 MW of electricity. Future developments are in advanced planning stages and propose to provide a further 5172 MW by 2020 (Cowrie, 2010). Coastal man-made structures in the region, including harbours and marinas have already suffered the negative effects of an invasive marine species. The carpet sea squirt *Didemnum vexillum* has established colonies in Wales and Ireland with likely transport routes occurring due to the high volume of leisure craft travelling between these coasts (Coelho 2010). Through smothering the surfaces it colonises *Didemnum vexillum* has a significant impact on local biodiversity and potential negative effects on economic activities, including colonising underwater aquaculture equipment, negatively effecting harvests of commercial species such as mussels (Coelho 2010). At similar artificial structures such as OWFs *Didemnum vexillum* would have an obvious negative effect. This would counteract biodiversity increases identified earlier as potential positive effects (such as turbine fouling organisms enhancing available food resources) if *Didemnum vexillum* was to colonize large areas of OWF pilings.

Shipping is shown to provide the primary method of transition of invasive species both within ballast water and on vessel hulls (Carlton and Geller, 1993). The continuous development of larger OWFs at progressively greater distances from the shore presents a logical series of stepping stones to aid the travel of marine invasive species between offshore shipping lanes and coastal locations (Apte et al. 2000, Adams et al. 2014). Monitoring of colonising species beyond the initial two to three years post-construction provided by environmental impact assessments is required. This would enable managers to be aware if increased regional alien and invasive species colonisation are likely to be a common threat. Early identification of invasive species would aid mitigation actions to address negative effects on biodiversity, survival of native species and economic activities across regions (Chapin III et al. 2000; Bax et al. 2003). Eradicating invasive species is more challenging in marine environments than terrestrial. Global and regional approaches to prevent spread of invasive species, particularly in ship ballast water are currently favoured management strategies (Bax et al. 2003). Successful approaches to eradicate species in marine environments have only been displayed if detection occurs shortly after arrival (Bax et al. 2002). Once a marine invasive species has become widely distributed there are no proven techniques to eradicate it (Bax et al. 2002).

Combined with the potential for promoting significant invasions of alien species this knowledge gap highlights a specific need for OWF communities and their influence on surrounding habitats to be rigorously and continuously monitored. Current EIA monitoring requirements provide an opportunity to specifically target presence of invasive species. Such monitoring requirements are supported due to evidence that invasive species associate quickly with un-natural habitats such as marine pontoons, sea walls, ship wrecks and oil rigs (Davis et al. 1983; Svane and Kjerulf Peterson, 2001; Underhill-Day and Dryrnda 2005). These structures share characteristics with OWFs, being both of man-made materials and located at sites where hard substratum was previously not found. EIA regulations for OWF developments require developers to show management measures are instigated to prevent the introduction of invasive non-native species. Despite this consideration, existing EIAs for OWFs refer to invasive non-native species (DONG Energy 2013), but specific testing for the presence of invasive species is not compulsory in EIA procedures (DECC 2009).

iii) Non naturally occurring species communities

Artificial structures in a variety of marine environments have been shown to support differing faunal assemblages to those naturally occurring in that location (Love et al. 1999; Connell 2001; Connor et al. 2004; Perkol-Finkel and Benayahu 2005; Clynick 2006, 2008; Wilhelmsson and Malm 2008). Perkol-Finkel and Benayahu (2005) report that an artificial reef community may remain different from a nearby natural reef community, even after 10 years. In a further comparison a 119 year old ship wreck also supported a distinctly different community after over a century submerged. This suggests that an artificial reef will only mimic its adjacent natural communities if it possesses structural features similar to those of the natural surroundings (Perkol-Finkel et al. 2006). Settlement panels placed on pontoons, pilings and natural rock reef habitats in Sydney, Australia displayed different communities on the artificial habitats in comparison to natural rock habitats (Connell 2001). A distinctive biotope has also been identified to occur on moderately wave exposed circalittoral steel wrecks in UK waters in comparison with sea bed habitat (Connor et al. 2004; Hiscock et al. 2010).

Species colonisation and community development on the *Scylla*, a steel shipwreck in Cornwall, UK produced a community that was distinctly different to nearby natural rock reefs five years after submergence (Hiscock et al. 2010). This location was environmentally similar to existing OWF sites in the UK. Significantly the shipwreck communities did not include some of the rare, scarce or threatened species that occur on local rock reefs (Hiscock et al. 2010). One author of this study also noted incidences of species being recorded from the wreck site that were previously unrecorded in the surrounding region (J Highfield, analyst and co-author, Hiscock et al. 2010, pers. comm.).

The evidence from these studies presents a combination of potential negative factors that should be taken into account when siting and assessing the effects of artificial structures in the marine environment. These factors also relate to consideration of effects of OWF structures on biological and socio-economic factors. Firstly, will the communities developing in association with the structure or footprint of structures benefit the naturally occurring habitat? Secondly, will the artificial structures and the footprint of these structures as a whole necessitate invasion of alien species, especially those that will have a negative impact on native species, communities and ecosystems? These factors are of further importance when considering the designation of an artificial structure as a marine protected area as they may directly affect MPA goals.

2.8 Habitat gains and losses.

Present evidence for ecological effects of OWFs suggests species assemblages on turbine pilings, surrounding scour protection and the sea bed up to 5 metres away are different to those existing previously at the site (Wilhelmsson and Malm 2008; Wilhelmsson et al. 2006). OWF turbines have been shown to provide the basis for communities similar to those found on bridge and pier pilings, dominated by filter feeders and increased abundance of mobile species that can exploit this resource (Hiscock 2002; Wilhelmsson and Malm 2008; Wilhelmsson et al. 2006; Langhamer 2009). The naturally occurring sand and shingle bank habitat that the majority of existing OWFs are located within supports species of ecological and commercial value. These include species supporting commercial fisheries such as gadidae family fish, flatfish, ray, crab, lobster and shrimp (Ellis et al. 2000; RWEnpower 2004; Vattenfall 2005). Loss of pre-existing habitat as a result of OWF construction is therefore likely to have some detrimental ecological and economic effects. The habitat gained from deployment of turbines and associated scour protection exceeds the area of habitat lost. Therefore, understanding ecological and economic losses and gains from provision of new habitat are equally important (Wilson and Elliott 2010).

Monitoring of benthic fauna inhabiting the sand bank habitats surrounding OWFs in the UK (Vattenfall 2005) and wave power marine renewable energy instillations in Sweden (Langhamer 2010) displayed changes in species occurrence and abundance within 2 to 5 metres of the instillation. Faunal assemblages at a distance from renewable energy structures continued to show greater similarity to pre-existing samples (Vattenfall 2005; Langhamer 2010). However, limited evidence exists, with few studies at multiple OWF sites that encompass a range of possible environmental conditions. This inhibits confidence relating these results across all sites. The effect of different hydrodynamic factors such as current strength and site location in relation to larvae transport pathways on the OWF communities identified in existing studies is not known. Due to the nature of larval dispersal in the marine environment very different species assemblages and related predatory fish and crustacean presence are possible at different OWF sites (Keough 1983; Goldson et al. 2001). Further studies are therefore required to assess the effects of OWFs as MPA within different locations with different oceanographic and biological parameters (Linley et al. 2007) (Table 2.2).

Table 2.2 Research needs identified through the literature review, feasibility of approaching an individual research need within the time and resource constraints of the thesis (given existing monitoring data (EIA) or fisheries data are available) is indicated as good, possible or low.

	Research needs identified	**Action:** collect existing data (ED) or primary data (PD) and feasibility, good ●, possible ○, or low ◊	
Ecological effects	Identify if species communities within OWF change over time	ED, PD (EIA data and fieldwork)	●
	Record fish colonisation at OWFs on a case by case basis	ED, PD (EIA data and fieldwork)	●
	Identify trends in species communities that can be attributed across OWF sites	ED, PD (EIA data and fieldwork)	●
	Identify ecological effects on neighbouring habitat	ED, PD (EIA data and fieldwork)	●
	Address need for long term monitoring of species communities	ED, PD (EIA data and fieldwork)	○
	Design long term monitoring with standardised methods across sites	ED (review best practice)	●
	Identify if OWF communities display similarity to naturally occurring communities	ED, PD (EIA data and fieldwork)	●
	Identify positive and negative effects of OWF communities on regional MPA network goals	ED, PD (analyse data and review)	●
	Assess presence and risk of invasive species	ED, PD (EIA data and fieldwork)	◊
	Identify the effect of, environmental and oceanographic factors on species colonising OWFs	ED, PD (EIA data and fieldwork)	○
	Assess change in species presence and abundance from angling data records	ED, (collate and analyse)	○
	Identify if production is occurring within OWFs for mobile species	ED, PD (EIA data and fieldwork)	◊
	Identify association of commercially important species with OWFs	ED, PD (EIA data and fieldwork)	●
	Identify association of different life stages of mobile species with OWFs	ED, PD (EIA data and fieldwork)	○
	Investigate if OWF communities change over time and what the benefits to MPA goals end communities may provide	ED, PD (EIA data and fieldwork)	○
	Management and mitigation requirements to maximise MPA benefits	ED, PD (literature, interviews and wrokshops)	○
	Identify which MPA benefits suggested in reviews are relevant for existing sites	ED, PD (EIA data and fieldwork)	○
	Relate how benefits and negative effects from existing sites may relate to future, larger OWFs	ED, PD (EIA data and fieldwork)	●
Resource user effects	Effect of OWFs presence on spatial fishing activity	ED, PD (fisheries data and mapping)	●
	Effect of OWFs on economic sustainability of local fisheries	ED, PD (fisheries data and interviews)	●
	Identify fishing grounds displaced fishing effort will be displaced to	ED, PD (fisheries data and interviews)	●
	Identify costs and benefits of OWF development to ecological and economic characteristics of a region	ED, PD (existing reports, EIA data and fieldwork)	○
	Identify if OWFs provide income for fisheries	ED, PD (landings, interviews)	●
	Survey experiences and perceptions of fishermen on effects of existing OWFs	PD (Interviews and workshops)	●

2.9 Positive effects of offshore wind farms

i) Effects of OWFs in the UK on fish abundance and diversity

Since enactment of the MCAA in 2009 offshore developments up to 100MW are dealt with under the Marine and Coastal Access Act 2009 and the Marine Management Organisation (MMO) is the main consenting body for these developments. A single 'marine license' system was instigated in 2009 that essentially combined the existing FEPA (environmental effects) and CPA (navigational safety) licenses. The single marine licensing system came into practice, succeeding the separate FEPA and CPA license system in April 2011, following rounds of consultation. The single marine license system streamlines the original FEPA and CPA license system, as well as incorporating new legislation since 1985, including the habitats and birds directives. The MMO will determine applications in accordance with the Marine Policy Statement and any applicable Marine plans, unless relevant considerations indicate otherwise (HM Government, 2009). However, the MCAA (2009) in S. 58 (3) indicates that this does not apply decisions made for developments of over 100MW. These developments fall under the Planning Act 2008 (c. 29).

All offshore generating stations over 100MW in the territorial waters of England and Wales and the renewable energy zones, together with the associated infrastructure are classified as Nationally Significant Infrastructure Projects (NSIP). The responsible authority for consenting decisions of generating stations offshore over 100MW and associated infrastructure is the Secretary of State for Energy and Climate Change. Decisions are made under the Planning Act 2008 Part 3-8, and the Infrastructure Planning Commission (IPC) handles these applications. The IPC was abolished under the Localism Act 2011 in April 2012, and its tasks transferred to the Planning

Inspectorate (PI) an Executive Agency of the Department for Communities and Local Government, which has largely the same functions.

Potential OWF environmental impacts are considered on a project by project basis as part of the planning process through the requirement for developers to undertake Environmental Impact Assessments (EIAs) and Habitats Regulations Assessments (HRAs) where appropriate.

When processing development applications for developments over 100MW, DECC considers the environmental consequences of proposals, applying European requirements for Environmental Impact Assessments (EIAs). Scoping of potential environmental impacts is undertaken through the completion of an environmental statement (ES).

Once consents have been granted to development applications, OWF licensing in the UK requires environmental assessments in reference to the topics identified in the ES and monitoring in respect to baseline (pre-construction) conditions. For existing OWFs during the course of this study (with licenses issued under the pre MCAA 2009 licensing system), environmental assessment was required under section 5 of the Food and Environmental Protection Act 1985 (FEPA), FEPA monitoring required pre and post-construction monitoring of sediment changes, benthic species / communities, fish species / communities, marine mammals and birds. Within the pre-existing license system (before the advent of the single marine license) FEPA monitoring requirements were capped at 3 years post-construction, substantially limiting the interpretation of ecological change as a result of OWF deployment (as limited temporal scales were monitored to observe change) (Walker et al. 2009; Fugro EMU, 2014).

FEPA related monitoring of before and after conditions at sites in the North Sea (North Hoyle) and Irish Sea (Kentish Flats) have reported no significant impacts to communities of fish species. Catches of commercial fisherman were reported to have initially decreased during construction adjacent to OWF sites but had recovered within 2 to 3 years (RWEnpower 2006). Environmental monitoring reports suggest annual variations in benthic infauna, benthic epifauna and fish communities represent wider regional fluctuations (RWEnpower 2006; Vattenfall 2006).

Although the FEPA monitoring requires before and after assessments, data collection is limited. Surveys only continue two to three years post-construction and baseline data are limited to one annual survey. Data sets on sediment, infauna, epifauna and fish communities were only required to examine if large scale changes had occurred and data sets were rarely analysed and interpreted in relation to each other (Walker et al. 2009; Fugro EMU 2014). This limits the applicability of reports for detailed ecological assessment of the potential for co-location of OWFs and MPAs to aid MPA goals.

As the only data sets on the effects of OWFs on fauna communities in the UK these data sets are however highly relevant to this thesis. The Kentish flats OWF FEPA reports do indicate increased catch per unit effort (CPUE) for all species caught in survey trawls within the OWF area compared to reference sites. Overall CPUE (all species calculated as one group) increased over the two year period of data collection, with only the flatfish, sole (*Solea solea*) displaying decreasing CPUE (Vattenfall 2004). This interesting trend is however inhibited by the short time period of monitoring**.**

The UK Centre for Fisheries and Aquaculture Science (Cefas) carry out annual survey trawls to monitor fish stocks in UK waters with a database since 1979 in the Irish Sea. One annual monitoring site, 6km from the North Hoyle OWF was reviewed up to 2004 (one year post-construction of North Hoyle OWF). CPUE of whiting and poor cod showed significant increases in comparison with the long term averages for the station (RWE npower 2004). Dab, plaice, sole and solenette catches also increased post-construction. However, it is important to note that any inferences of increase in abundance are based on the first year post-construction. Many other factors may contribute to these changes in abundance beyond OWF related effects, including such short term effects as greater prey availability as a result of ground disturbance during construction (Kaiser and Spencer 1994; Groenewold and Fonds 2000). Also the Cefas monitoring site is not at the OWF site itself and although the data would indicate very broad-scale effects from OWF development it may not indicate more subtle or site specific changes (Walker et al. 2009). Continued monitoring and detailed assessment of commercial species population trends within the site, and at progressively greater distances outside would provide the means of assessing these observations further.

Reports within the North Hoyle post-construction FEPA monitoring of consultation with angling charter vessels suggest species benefits have occurred from OWF presence. Vessel operators claim to have consistently used marks in close proximity to the North West boundary of the OWF since construction. This area was reported to provide good catches of small cod, whiting, skate, thornback ray, dogfish, tope, plaice, dab, flounder, mackerel, black bream and ballan wrasse one year after the OWF was constructed (RWEnpower 2004). The report summarises that Rhyl charter fishermen recognise the site may prove beneficial to their business (RWEnpower 2004). These anecdotal accounts support the evidence from Cefas survey trawls. Angling records have also been shown to provide a valid means of providing historical time series data sets for assessing fish presence in relation to MPAs (Blyth-Skyrme et al. 2005; Richardson et al. 2006). The monitoring focuses strongly on recreational fishing impacts, analyses of commercial fishing activity and landings data and angling data records would offer a more detailed data source in assessing the impact of OWFs on fish occurrence.

North Hoyle is currently the longest running operational OWF in the UK and early monitoring reports provide indications of positive ecological and socio-economic effects of an OWF. The region is an important nursery ground for flatfish and gadoid species (Coull et al. 1998; Ellis et al. 2012). Despite potential negative effects from disturbance and physical alteration of naturally occurring habitat, the positive effects of reducing fishing effort within a sea area and increasing habitat complexity may be possible factors influencing these observed increases in CPUE. In reference to the OSPAR goals of a successful MPA, the aim of '*protecting and conserving species'* is potentially attainable if these initial results prove to be consistent over a greater time scale. The goals of the UK marine conservation zone network to '*protect marine life while allowing sustainable and legitimate use of seas to continue,'* (JNCC 2013) are also supported by this evidence. Detailed long term monitoring is required to establish if these perceived environmental and economic benefits continue beyond one or two years post-construction.

2.10 Artificial reefs in the UK and Europe.

Previous studies of artificial structures deployed in UK waters have focused on Poole Bay artificial reef in Dorset, UK (Jenson et al. 1994; Fowler et al. 1998) and Loch Linnhe artificial reef in western Scotland (Sayer et al. 2005; Beaumont 2008; Hunter and Sayer 2009). These studies were conducted in relevant inshore locations and with spatially similar design and materials to OWFs. They also offer a greater historical perspective than short term FEPA reports of the effects of artificial structures on faunal communities and commercial species. Jenson et al. (1994) report the Poole Bay reef (blocks constructed of coal fired power station waste, pulverised fuel ash and gypsum) did not affect the infauna population in surrounding habitats. Instead the reef was rapidly colonised by epibiota, with a progression in the number of species present and a maturation of the epibiota populations similar to those seen on nearby natural reefs (Jenson et al. 1994). Jenson et al. (1994) also supported the evidence that abundance of species supporting commercial activities are enhanced by artificial reefs. There was rapid colonization of the Poole bay artificial reef units by adult European lobster (*Homarus gammarus*) and brown crab (*Cancer pagarus*) within three weeks of deployment. Crab and lobster occurrence was further investigated with acoustic and conventional tagging studies to reveal some lobsters displayed site fidelity to the reef (Jenson et al. 1994).

A similar pattern is recorded in specific studies of fish occurrence at Poole Bay reef. Pouting (*Trisopterus luscus*), a small gadoid fish were recorded by Jenson et al. (1994) shoaling around the Poole Bay reef by day and scavenging in surrounding sand bank habitats at night. Shoal size was estimated at around 200 individuals at just one of the eight reef units, presenting a high biomass of this species. Demographic assessment and tagging studies of this pouting population confirmed dusk to dawn emigration of the occurred. Tagged fish were also observed on the reef for up to five days suggesting that the artificial structures may act as a 'home reef' for this population (Fowler et al. 1998). The physical presence of the reef units was suggested as providing shelter from stronger currents, as the shoals congregated around structures when tidal currents were highest and then dispersed during periods of weaker currents (Fowler et al. 1998).

The Poole Bay artificial reef therefore appears to have enhanced diversity and abundance of larger predators and scavenging species due to the availability of additional habitat for shelter (Jenson et al. 1994; Fowler 1998). This artificial habitat appears to provide the role of natural habitats worldwide such as coral reefs to mangroves, natural rock reefs and even sea mounts.

The structure provides shelter from currents; therefore reducing metabolic expenditure when resting as well as reducing vulnerability to predators (Philips and Joli 1984; Rooker and Dennis 1991; Nagelkerken et al. 2000; Auster et al. 2005). Availability of shelter may therefore provide a more important factor than presence of food resources to explain the occurrence of some fish and crustacean species at artificial reefs and OWF structures (Rooker and Dennis 1991).

The benefits of increased faunal assemblages of fish and crustacean species are also evident at the large artificial reef experimental site at Loch Linnhe in western Scotland. A thirty fold increase in faunal biomass was recorded after construction as well as occupation of the site by large schools of fish (Beaumont, 2008). Research questions remain as to whether occurrence of species at these artificial sites will lead to production, increasing the stock within a region or simply attract individuals from surrounding habitat. If attraction on its own occurs this would reduce populations available for exploitation and recruitment in surrounding areas, but would potentially concentrate the resource in one easily attainable location (Pickering and Whitmarsh 1997; Bortone 1998; Svane and Petersen 2001). Understanding if production or merely attraction occurs at these sites and within OWFs will be relevant to identifying if sites support MPA goals.

2.11 Production attraction debate at artificial structures

The benefits occurring from artificial structures could be attributed to OWFs which occupy similar coastal locations, cover similar spatial area and incorporate similar materials. Loch Linnhe and Poole Bay artificial reefs reveal the potential of artificial structures in the UK to conserve species if sufficient management is in place. However the question is whether those resources are emigrating from surrounding habitats, therefore concentrating the regional population and not aiding recruitment in the region, or if regional abundance is increasing with available habitat (Bortone 1998; Svane and Petersen 2001; Pickering and Whitmarsh 1997).

At Poole Bay some species have been identified to be reproducing at the site, (typically species that seek reef habitat at multiple life stages) such as corkwing wrasse (*Crenilabrus melops*), lobster (*Homarus gammarus*), spiny spider crab (*Liocarcimus puber*), hermit crabs (*Pagurus bernhardus*), whelks (*Bercinum undatum*) and nudibranchs (*Archidoris pseudoargus*). This evidence suggests that artificial habitats suitable for adaptation as scour protection in OWFs (Wilson and Elliott 2009) can provide a production role as well as attraction.

In both production and attraction cases however it would appear important to establish sustainable management regulations on extractive activities such as commercial fishing. As discussed, it is important to consider that a large population of a species may be concentrated in a small region, allowing a considerable proportion of the adults of reproductive age to be removed from the population by a fishery in a short space of time (Pickering and Whitmarsh 1997; Bortone 1998; Svane and Petersen 2001). This scenario has been proposed to have caused the rapid commercial extinction and threatened conservation status of commercial species worldwide (Coleman et al. 1996, Sala et al. 2003). Due to the huge scale of potential OWF developments it is important to understand if and how commercially exploited species in a given region utilise OWF habitat. Knowledge on the association of species with OWFs at different life stages and in relation to feeding and resting behaviours is also important to inform MPA designation and management decisions (Table 2.2).

Existing studies of artificial structures display that structures and materials representing natural habitat are likely to aid in enhancing biomass of regionally occurring species (Perkol-Finkel et al. 2006).

The question of whether this increase in biomass was a result of fish aggregating to feed or utilise a structure for feeding or shelter has been tested in previous studies. Alvezion (1989) monitored fish populations at artificial reef units and surrounding patch reef from the time the artificial units were first deployed. Fish populations at surrounding patch reef stayed the same despite significant populations also developing at the artificial reef sites, suggesting that populations are habitat limited (Alvezion 1989). Similarly, the results from Jenson et al. (1994) showed that some of the lobsters occurring at Poole Bay artificial reef remained loyal to the site, while others only settled for short periods of time. This supports the theory that artificial structures have potential to recruit independent populations from surrounding habitat, therefore increasing regional abundance of species.

A combination of monitoring surrounding reef habitat before and after construction of artificial OWF related habitat and tagging, telemetry and tracking experiments would provide a means of examining attraction and production in relation to OWF structures. Recently, examination of stomach contents of fish aggregating around OWF pilings in the Belgium North Sea displayed fish were feeding on species present on the pilings (Reubens et al. 2014, 2014a). Tagging and telemetry studies displayed cod (*Gadis morhua*) showed some association with the location of OWF pilings. Tagged sole (*Solea solea*) however, showed little association with habitat created in the OWF (Winter et al. 2010). Such research is required, in addition to monitoring of regional population demographics before and after OWF construction, to understand the potential benefits or disadvantages to regional populations and abundance from co-location of OWFs and MPAs.

Current evidence suggests that OWFs and similar structures (that have not been designed specifically to increase natural habitat) may potentially only increase abundance and diversity of species which can utilise and - or adapt to the OWF structures. The scale dependent and species specific responses noted for marine renewable energy instillations in Sweden (Langhamer et al. 2009) need to be considered in decisions to utilise OWFs to achieve MPA goals. Other studies of habitat type in the North East Atlantic reiterate correlations between prey abundance and fish biomass to be habitat associated (Stal et al. 2007). Naturally occurring hard substratum has been shown to provide higher mean species number and abundance of fish prey resources and associated higher abundance of fish species (although diversity was similar throughout habitats) (Stal et al. 2007). The increase of hard substratum surface area within OWF footprints, especially with the use of natural rock or concrete scour protection would be likely to lead to species specific abundance increases. Understanding species specific responses for predator and prey species is essential in evaluating the sustainability of populations to fishing activities and potential benefits from designation of MPAs in relation to OWFs. This, again, identifies a need for more detailed regional surveys where OWF development is present, to conduct comparisons of species presence and abundance at naturally occurring habitats with those at the habitat created by OWFs.

2.12 Marine protected areas and fisheries closures

Marine reserves that have closed an area to some or all of extractive activities serve to either rehabilitate damaged habitat, allow exploited species to recover or protect rare or threatened ecosystems or biomes (Roberts et al. 2001, Sale et al. 2005, Barrett et al. 2007). OWFs may potentially cover over 6000km^2, leading to concern within the fishing community that large areas of fishing grounds will be lost (Mackinson et al. 2006). Traditional fishing practices in each region such as towed nets, set nets and long lines are considered to be impractical due to the risk of entanglement (Mackinson et al. 2006). Fundamentally this is the reason behind claims that OWFs provide accidental or '*de facto'* closed areas, and may provide similar conditions to specifically designed marine reserves (Linley et al. 2007; Inger et al. 2009; Punt et al. 2009; Wilson et al. 2010).

Much of the evidence for *de facto* benefits is theoretical, based on studies of existing reserves that have been specifically designed for conservation of habitat, species or fisheries augmentation. Even when assessing specifically designed marine reserves there is debate over their effectiveness, especially as fisheries management tools. This is due to the limited evidence base as globally there are low numbers of effectively managed reserves, and a lack of rigorously designed before and after studies (Willis et al. 2003; Sale et al. 2005; Kareiva 2006; Hart and Sissenwine 2009). However, a review by Halpern (2003) of all before and after studies or inside outside comparisons of full no-take zones concluded that evidence was considerable that regardless of their size, marine reserves led to increases in density, biomass, individual size and diversity in all functional groups. This claim would suggest that despite the location, whether designed or accidental the limitation of a sea area to extractive activity will benefit the species occurring in that habitat. Halpern's (2003) findings are supported in review articles by Gell and Roberts (2003, 2003b), whilst Russ et al. (2009) showed the world's largest marine reserve network (the Great Barrier Reef Marine Park, Australia) produced not only significant increases in fish abundance but did so within eighteen to twenty four months of protection. Evidence also exists that the build-up of mobile individuals and nektonic larvae within marine reserves emigrate outside the reserve boundaries to enhance abundance and diversity of organisms in surrounding habitats (Bohnsack et al. 1996; Johnson et al. 1999; McClanahan and Mangi 2000; Roberts et al. 2001)

Beneficial reserve effects are also reported in locations comparable to the principal OWF development sites in the North Atlantic, including the 1994 Georges Bank closed area in the North West Atlantic (Murawski et al. 2005), Lyme Bay closure, UK (Mangi et al. 2011), Lundy Island no take zone, UK (Wootton et al. 2012) and Start Point inshore potting agreement, UK (Blyth-Skyrme et al. 2005). Studies of fisheries related effects exist for the largest and smallest of these reserves. The 340km^2 Start Point 'inshore potting agreement' and the 17000km^2 Georges Bank area closure revealed beneficial results were identifiable at both sites. Larger sized individual fish were caught from within the reserve compared to outside in studies of the Start Point Inshore Potting Agreement (Blyth-Skyrme et al. 2005). Large scale increased abundance within populations or increased catches of commercial fish in adjacent areas were evident in relation to the Georges Bank Closed Area (Murawski et al. 2005).

Linley et al. (2007) and Inger et al. (2009) reveal a range of specific beneficial MPA-related effects from the development of OWFs in the marine environment. These benefits extend on the findings of existing studies such as Blyth-Skyrne et al. (2005) and Murawski et al. (2005). Benefits are summarised as:

1. The recovery of grounds damaged by benthic towed fishing gears leading to enriched benthic biota (Kaiser et al. 2006), so providing direct fishery benefits (Auster et al. 2002, Rodwell et al. 2003).
2. The majority of MPAs regardless of size enhance fish populations (Halpern 2003; Claudet et al. 2008).
3. MPAs designated in locations without prior design or intent to conserve biodiversity or enhance fisheries are still shown to protect fish stocks within the MPA (Friedlander et al. 2007).

4. Marine species show high levels of connectivity with individuals moving between populations at various life stages. OWFs as MPAs can therefore still be expected to provide net export of fish larvae, or recruitment subsidy (Gerber et al. 2003) and emigration or 'spillover' of juvenile and adult fish (DeMartini 1993; McClanahan and Mangi 2000)
5. Therefore OWFs as MPAs have the potential to bolster fisheries in the surrounding region (Sale et al. 2005).
6. In a region suffering from degraded resources MPAs offer a cost effective means of restoring habitats and populations (Balmford et al. 2004).

There are counter arguments to these positive claims however, especially in the application of OWFs as MPAs. Claudet et al. (2008) provide evidence that the effectiveness of marine reserve is size and age dependant, especially for fisheries management. An MPA network including OWFs may be limited in achieving conservation goals as OWFs have been present for a limited time. Inger et al. (2009) also reiterate that habitat type (Friedlander et al. 2007), habitat quality (Auster et al. 2002; Rodwell et al. 2003) and efficacy of MPA management regimes (Burke et al. 2002; Samoilys et al. 2007) are also key to success. If OWFs are simply constructed and the biological resources inside the footprint and activities within the region left un-managed, the existence of the structures may do little to reach the potential MPA related benefits that appear possible for OWFs. Application of zoning with limitation on extractive activities such as fishing within areas or the entire region of an OWF may be beneficial (GBRMPA 2003). Selection of construction and scour protection materials that aid increases in abundance of regionally important, or commercially exploited species provide a further management option (Wilson and Elliott 2009). To aid site specific measures that aid the requirement for mitigation of existing marine activities and regional marine planning, stakeholder consultation (bottom up) approaches would be applicable (Jones et al. 2011). Effective enforcement is raised as key to MPA success (Samoilys et al. 2007). The infrastructure of an OWF provides an obvious means of indicating the borders of an MPA that is sited within an OWF (co-located), thereby aiding enforcement.

It appears imperative at this stage that the positive and negative effects that are evident for global MPAs are investigated in relation to the current operating OWFs, in order to establish which effects are relevant for these structures. OWF site choices are formulaic in nature, requiring sandbanks in shallow enough regions to allow economically viable construction methods, and access for supply and maintenance (Linley et al 2007, 2008). The similarity of sites within a development region may mean that large ecological effects identified for current inshore OWFs are potentially transferable to larger sites further offshore. Sites such as North Hoyle in the Eastern Irish Sea and Kentish Flats in the Southern North Sea have been operating for nearly a decade and biodiversity effects and related fishery effects should be well established. Although much smaller (at 30 turbines each) than the proposed future OWFs such as Dogger Bank (over 2500 turbines) the community types colonizing the pilings, and fish and mobile crustacean species using the habitat may be similar. The techniques and tactical responses of fishermen and angling charter vessels to changing abundances and diversity of fish species and loss of areas of fishing ground are also likely to follow similar patterns. If different biological patterns and related fishing activity were to occur at the smaller sites, the necessary mitigation and management requirements identified should still be applicable to these larger sites.

The presence of OWF infrastructure and turbines themselves create a physical barrier to fishing activity, in particular, mobile trawled gear (Mackinson et al. 2006; Blyth-Skyrme 2010). This supports proposals to co-locate MPAs with OWFs from the fishing industry to limit loss of accessible grounds (Blyth-Skyrme 2010). The presence of the OWF structures creates a physical boundary that would ease the task of monitoring illegal fishing activity (if the OWF is designated a complete MPA). This is especially relevant in regard to smaller fishing vessels that currently do not carry on board vessel monitoring systems to aid enforcement. Offshore MPAs (beyond sight of land) currently rely on infrequent local fisheries enforcement vessel patrols, or aerial surveillance to police smaller vessel activity within a designated MPA. Co-location of an MPA with an OWF would ease practicalities of enforcement and reduce enforcement costs. The frequent supply boat and maintenance traffic will also act as a deterrent to illegal fishing.

Theme two: Effect of OWFs on a primary resource user

2.13 Fishing effort displacement.

Few studies have assessed the effects of developments, marine management measures or changes of human use within areas of the marine environment, by simultaneously taking into account biological resource changes and socio-economic issues. The impact on resource users such as fishermen stands to be very large due to the size and extent of OWFs across European seas. The many thousands of square kilometres set aside by The Crown Estate in the UK alone as OWF licensing areas will significantly reduce fishing effort and increase complex structures within UK waters (Crown Estate 2010). These developments will have effects on displacement of fishing effort into remaining fishing grounds (Dinmore et al. 2003). Combined with habitat and species effects of OWF development, displacement of fishing effort will increase ecological and economic concerns in a region (Dinmore et al. 2003; Hutton et al. 2004; Hiddink et al. 2006; Kaiser et al. 2006; Greenstreet et al. 2009).

OWFs have been developed with some consideration of existing fishing activity, as required by consenting procedures. OWF location choices have possibly been constrained by availability of economically viable construction sites. Such sites require wind rich regions on suitable sea bed for construction with access to suitable ports (Linley et al. 2007, 2008). The early round one OWFs in the UK were constructed in inshore regions that did not support intense fishing pressure (RWEnpower 2004; Mackinson et al. 2006). The larger round two and round three UK OWFs will inevitably further limit available fishing grounds as fishing fleets and recognised fishing grounds exist in all OWF development areas (Mackinson et al. 2006). Vessels and fleets are likely to encounter effects from OWF sites. Potential effects include: navigational changes, increased steaming times and fuel costs, effects on catches, fishing locations, changes in gear choice and tactics through to numbers of crew employed, income available from fishing and even long term career decisions such as leaving fishing altogether (Mackinson et al. 2006; Blyth-Skyrme 2010).

Consideration of effort displacement and the knock on effects on area closures is increasingly being called for when considering the overall ecological impacts of MPAs on a wider region (Hutton et al. 2004; Hiddink et al. 2006; Greenstreet et al. 2009). Prior to area closures fishers will have made decisions on spatial locations of operation on the basis of past catch rates (Hutton et al. 2004). Therefore, it can be assumed that if an area is closed boats successfully utilising that ground at particular seasons will be forced to search for new, less familiar grounds, incorporating greater fuel costs and less predictable catches during that period.

Hiddink et al. (2006) modelled the effect of redistribution of beam trawl effort on benthic communities following assumed area closures in the North Sea, using the assumption that fishers select grounds based on their knowledge of past catches. The random utility model used predicted redistribution to assess impacts to biomass, production and species richness of benthic communities. The model incorporated a trade-off between the negative impact on open areas and the recovery of closed areas. The findings of this study suggested that closure of lightly fished areas had the strongest positive effect. Closing large areas, especially those receiving high fishing pressure concentrated that effort within smaller spatial scales, increasing the regional impact on benthic communities. It was also suggested that without reducing allowed fishing effort concurrently with area closures positive effects of the area closure may be outweighed by negative impact of the redistributed effort (Hiddink et al. 2006).

Greenstreet et al. (2009) reiterate this point for fish catches and related fish abundance in a more recent model of fishing effort displacement from an MPA in the North Sea. As identified by Hiddink et al. (2006), the local gain within the MPA was negated by fishing effort displacement into the remaining open areas. A similar suite of management regulations were suggested, combining area closures with reductions in total allowable catch. With quotas already at non economically viable levels for many coastal fishing boats in the UK (Hansard 2002), the measures suggested by these studies to negate the impacts of effort displacement on benthic fauna in remaining areas and regional fish stocks would appear to increase economic pressure on the declining inshore fishing fleet in the UK.

Understanding the efficacy of OWFs within the UK's marine conservation zone network requires the effects on the region as a whole to be considered and the knock-on effects on livelihoods supported by those resources (JNCC 2013). A full analysis of fishing activity impacts from existing and future OWF sites would be required to assess how fishing tactics are changed by the presence of OWFs. Mapping of redistribution of effort would allow the knock-on effects of effort displacement on habitats and fish stocks to be assessed, therefore providing a region-wide holistic view of identified potential and negative MPA effects of OWFs. Future OWFs can then be assessed on a case by case basis whereby, given the pre-construction fishing practices and effort distribution the potential effort displaced onto neighbouring grounds can be predicted. The ecological and economic consequences of potential effort distribution can then be assessed (Table 2.2).

Hiddink et al. (2006) found that closure of lightly fished areas has the greatest overall benefit for regional benthic fauna are positive for many of the smaller scale round one OWFs. However, these findings may be negative for the future, larger scale developments. It appears important to know the fishing practices used and the species targeted by local fisheries, as well as the likely by-catch and benthic habitat impact of vessels prior to OWF construction. Together with evidence of effort displacement patterns, this information will allow assessment of effort displacement related impacts from future sites and the potential extent of habitat recovery within OWFs and MPAs from past benthic disturbance (Hiddink et al. 2006; Kaiser et al. 2006).

Existing OWF sites provide the opportunity to analyse existing changes and subsequent impacts in relation to displaced fishing effort. Costs and benefits to ecological and economic characteristics of sea areas receiving fishing effort in a region need to be understood to fully assess the potential of OWFs as MPAs.

2.14 Social and economic effects of OWFs on resource users

Full socio-economic studies of the impacts of OWFs are lacking, existing post-construction monitoring has only recorded meetings and discussions with local fishermen (RWE npower 2006; Vattenfall 2004). With the development of larger OWF sites, socio-economic surveys and monitoring have been adopted at many of the future development sites in the UK, often directly as a reaction to the concerns expressed by effected fishing communities and proposed need for compensation (P Crone, RWE Group, pers. comm.). Fully understanding the social and economic impacts as well as the biological impacts are central to assessing the relevance of OWF as MPAs. Other economic options may be available to fishermen in OWF development areas, such as providing service boats for involvement with the practical maintenance work at sites and guard boats during construction (Blyth – Skyrme 2010).

Therefore, OWFs present a more complex social and economic scenario than typical closed areas or standard quota or effort restrictions.

Cefas have conducted preliminary fisher socio-economic assessments using questionnaires and workshops to quantify fishermen perceptions of OWF effects (Mackinson et al. 2006). Weighting of questionnaire responses produced concise reactions to OWF development, with loss of existing fishing grounds accounting for the highest weighted negative factor. Potential creation of fish nursery area and MPA benefits were identified as the greatest perceived positive impact (Mackinson et al. 2006) (Table 2.5).

Table 2.5 Impacts and Opportunities revealed by Mackinson et al. (2006) from fisherman questionnaires on perceived effects of OWFs on fishing, the highest weighted responses (most often raised) are at the top of each list.

	Impacts	Opportunities
Highest (most often raised)	● Loss of fishing ground	● Creation of protected area, nursery area for speices
	● Have to move or find new ground	● Fishing opprotunities for static gear including angling
	● Increased competition and conflict	● Opportunity for tourism (boat trips to OWFs)
	● Increased fuel costs and reduction of time spent fishing	● Search for new grounds may result in finding high quality grounds
	● Cumulative effects from existing factors as well as OWFs	
	● Compromised safety	
	● EMF and Noise effecting fish	
Lowest	● Stress and negative influence on family	

Earliest UK OWFs had been in operation for over 6 years at sites in the UK when this literature review was conducted. A questionnaire, interview and workshop-led survey, revisiting impacts and opportunities that have been encountered by fishermen in regions with operating OWFs, would provide a useful comparison to the findings of Mackinson et al.

(2006). Utilising fishermen’s experience and knowledge would also provide a means of assessing socio-economic aspects alongside data on fish catches, landings and operational costs (Daw 2008). Current existing reports of socio-economic surveys have focused on mitigation and compensation led discussions between fishing communities and OWF developers on the impacts of sites (RWEnpower 2004, 2006; Vattenfall 2004; Blyth-Skyrme 2010). Currently there appears to be little retrospective analysis of the actual effect of OWF developments on fishing activity and catches and the resulting social and economic impacts of sites, especially in regard to the perceptions identified by Mackinson et al. (2006).

Studies in Scotland have displayed continuity across English, Welsh and Scottish fishermens perceptions of effects (Mackinson et al. 2006; Alexander et al. 2013). At the time of writing no studies have provided detailed assessment of changes in activity, catches and perceptions before and after large scale OWF development. Studies of fishing effort and catch rates at European artificial reefs indicated that fishermen utilising the reefs were gaining profitable catches (Ramos et al. 2006). Studies of fishing effort around offshore structures such as oil and gas rigs have also shown increased catches (Lokkeborg et al. 2002). Applicable methods for gathering fishermen‘s knowledge and experience have been developed in USA and the UK to collect information for MPA designation (Wilen and Abbot 2006; de Clers 2010). These methods use face to face interviews and mapping of fishing grounds to record current fishing grounds and knowledge of ecological patterns in the fishery, as well as knowledge of habitats in the region (Wilen and Abbot 2006; de Clers 2010). These methods could be adapted to provide information on fishermen’s perceptions of changes in fishing activity, species distribution and catches, before and after construction of OWFs and mapping of grounds used before and after construction.

2.15 Summary and identified research needs

OWF turbine pilings and surrounding scour protection at certain sites have been shown to support different faunal communities, in comparison with typically occurring natural habitat (Wilhelmsson and Malm 2008). Locally occurring fish and crustacean species have been recorded in high abundance at certain OWF and related MRE sites (Langhamer and Wilhelmsson 2009; Wilhelmsson et al. 2006; Reubens et al. 2010, 2013). With many of these species being of commercial value, there is potential to augment populations at that location and potentially benefit fisheries in the short term. The increase in biomass and physical deterrent to extractive activities from OWF infrastructure, such as turbine pilings will aid protection of these species and communities. This may aid MPA goals if OWFs are designated as strict no fishing zones. Alternatively utilising all or part of an OWF as a restricted fishing area may be beneficial if applied within a wider MPA with zoned access restrictions (GPRMPA 2006).

The key research questions relating to understanding the potential for co-locating OWFs and MPAs are identified in Table 2.2. The following paragraphs summarise the strengths and weaknesses of the current literature and associated evidence to approach evidence needs and the research opportunities to address gaps.

<u>Research gaps ecological effects</u>

- *Identify if species communities within OWF change over time*

  Strengths (existing research): Environmental monitoring was required for UK OWFs constructed before 2009 under FEPA license requirements (and under MMO single marine license conditions since April 2011 and Planning Inspectorate (PI) requirements for developments over 100MW). This provided data collection on benthic, infauna and epifauna, fish species and resource user effects, applied to individual OWF sites. Peer reviewed research on benthic communities and mobile fish and crustacean species abundance at OWFs and other MRE developments sites in comparison to control sites has been published for sites within European seas (Reubens et al. 2010, 2013; Langhamer, 2010; Wilhelmsson and Malm, 2010; Andersson and Ohman, 2010; Langhamer et al. 2009; Langhamer and Wilhelmsson, 2009; Wilhelmsson et al. 2006).

Weaknesses (existing research): Limitations in existing environmental monitoring are identified by Walker et al. (2009). Many monitoring programmes examine only the first 2-3 years post-construction (in addition to baseline and construction data). The data collection is limited in certain cases to one short period of data collection annually. Interactions between changes in benthic infauna, epifauna and fish are rarely interpreted thoroughly (Walker et al. 2009). Data sample sites for each data set are sometimes at different locations preventing comparison. Environmental and oceanographic data were rarely collected in relation to fauna samples, preventing analyses to separate natural effects from the effects of OWF construction. Data collection methods and sampling strategies from environmental monitoring were also not consistent between sites.

Existing peer reviewed journal studies provided a greater depth of detail, sampling either or all of: benthic infauna, epifauna or fish presence, with comparisons to surrounding habitats. These studies provided a detailed examination of the colonising communities on OWF structures (pilings) and the potential influence on surrounding habitat. Sampling techniques such as direct observation and recording of species presence by scuba divers allowed for data collection at much finer spatial resolution, and sampling at piling structures themselves. Weaknesses are identifiable as studies were conducted post-construction providing no comparison to pre-construction conditions. Sampling design focused on small spatial scales, for instance, species communities were sampled on pilings and seabed habitats up to twenty metres from the piling (Andersson and Ohman 2010; Langhamer 2010; Langhamer et al. 2009; Wilhelmsson and Malm 2008; Wilhelmsson et al. 2006).

Opportunities (for developing original knowledge): Analyses of existing data and original data collection are required that investigate changes in species communities over time. Such studies could make use of the existence of (all be it limited) data on pre-construction and post-construction species communities from environmental monitoring. This would provide studies at the scale of entire OWFs in comparison to control sites outside the OWF. Such a comparison would include control samples that are at greater distances from the development than existing peer reviewed studies have investigated. This is beneficial as it is possible that post-construction species communities, even at a distance from pilings may have changed from pre-construction conditions. There are also opportunities for interpretation of data sets from pre-construction and post-construction benthic infauna, epifauna and fish samples in relation to each other and, where data exists, in relation to environmental conditions. This analysis would approach separation of natural effects from OWF development. Extending monitoring periods by re-visiting a previously studied site that has been present for over 5 years would raise further opportunities. This would allow identification of further changes to fauna communities with time post-construction. Interpretation of the potential species, communities and therefore biological resources that would benefit from protection within a co-located MPA could then be made.

The opportunities identified for developing original knowledge would benefit the following knowledge needs, identified in relation to establishing the implications of co-location of OWFs and MPAs:

- *Identify trends in species communities that can be attributed across OWF sites.*
- *Identify ecological effects on neighbouring habitat.*
- *Design long term monitoring with standardised methods across sites.*
- *Identify if OWF communities display similarity to naturally occurring communities.*
- *Identify positive and negative effects of OWF communities on regional MPA network goals.*
- *Identify association of commercially important species with OWFs.*
- *Relate how benefits and negative effects from existing sites may relate to future, larger OWFs.*

Research gaps resource user effects

Strengths (existing research):

Research into resource user effects of OWFs has been limited to discussions with fishermen, required as a consideration in environmental monitoring programmes. One study has identified perceived impacts of larger OWFs on the fishing industry using fishermen interviews (Mackinson et al. 2006). Workshops and discussion with industry groups have also led to identification of mitigation options (Blyth-Skyrme 2010).

Weaknesses (existing research):

A large evidence gap exists to investigate changes in fishing activity and catches in association with OWF developments. Existing monitoring provides limited sample sizes and structured surveys. The in-depth study by Mackinson et al. (2006) and reports of workshops (Blyth-Skyrme 2010) provide valuable identification of issues and potential mitigation solutions, but do not provide investigation of before and after changes to examine if perceived effects have been experienced.

Opportunities (for developing original knowledge):

There is opportunity for a study that utilises the in-depth interview and questionnaire approaches of existing studies, but applies them to investigating before and after effects (Mackinson et al. 2006, Blyth-Skyrme 2010). A number of data sources exist for surveillance of fishing activity which can be adapted to quantifying spatial fishing effort (Vanstead and Silva 2010). These spatial fishing activity data sources could be applied to investigate changes in spatial fishing activity, over before and after OWF construction periods.

The opportunities identified for developing original knowledge would benefit the following knowledge needs, identified in relation to establishing the implications of co-location of OWFs and MPAs:

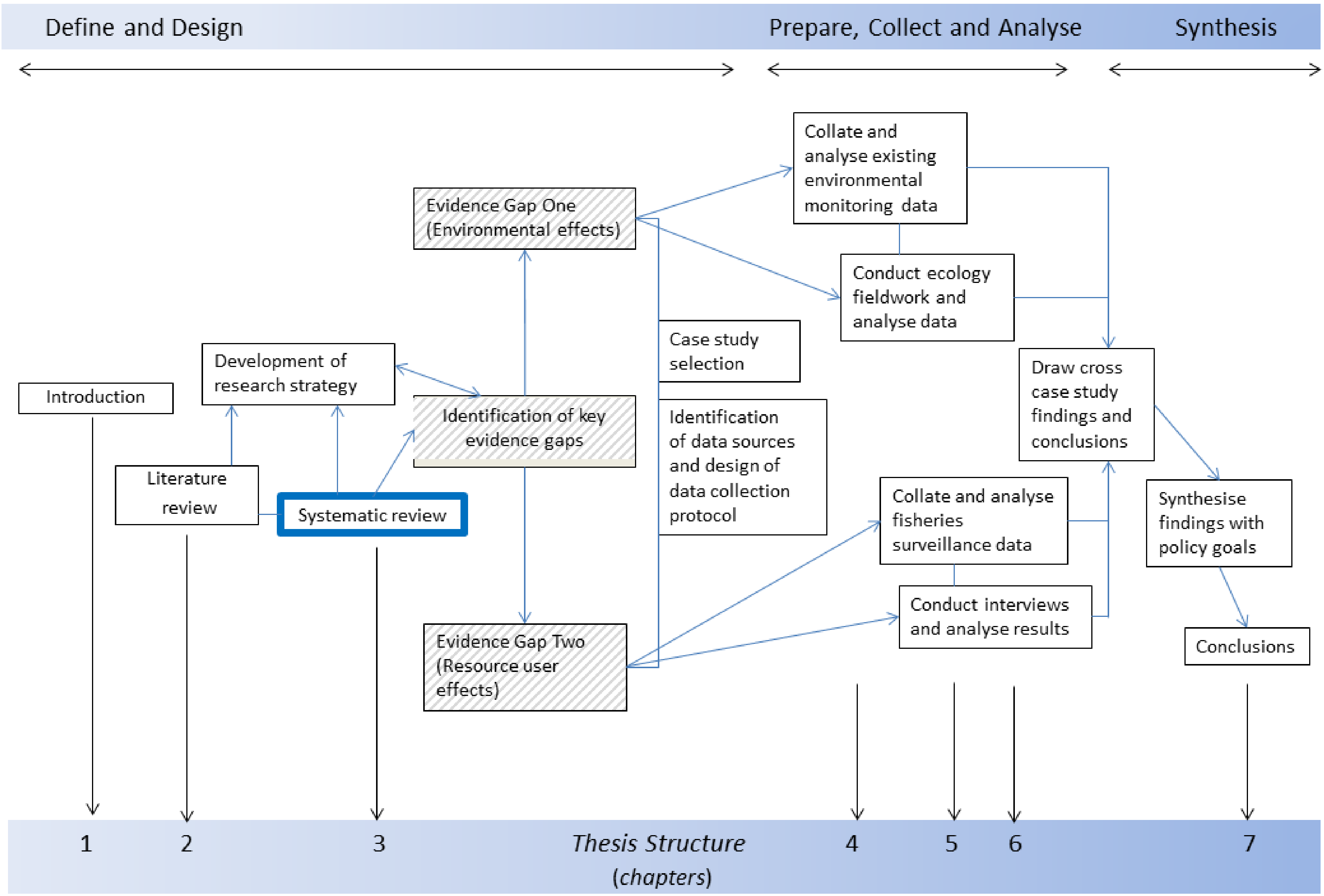
- *Effect of OWFs presence on spatial fishing activity.*
- *Effect of OWFs on economic sustainability of local fisheries.*
- *Identify fishing grounds displaced fishing effort will be displaced to.*
- *Identify if OWFs provide income for fisheries.*
- *Survey experiences and perceptions of fishermen on effects of existing OWFs.*

A full multidisciplinary study is required however, to assess if the early evidence of positive effects continues as structures are in the water over increasing time periods. Studies are also required on region-wide effects if fishing activities are displaced to surrounding areas.

Alternative uses of OWF sites including fisheries mitigation such as aquaculture (Linley et al. 2007; Syvret et al 2013), or manipulating OWF structures to enhance abundance of particular species (Langhamer 2010) may need to be adapted to successfully incorporate OWFs in an already crowded marine environment (Ehler and Douvere 2006).

Within the UK, evidence of the ecological and socio-economic effects of OWFs has been developed from reviews of processes at comparable artificial structures and area closures (Hiscock 2002; Gill 2005; Linley et al. 2007, 2008; Inger et al. 2009; Wilson et al. 2010). The knowledge gaps and research opportunities to inform planning and MPA co-location decisions raised by this literature review still cover a large number of questions (Table 2.2). A multidisciplinary study of changes in biology, ecology, fishing practices and resulting socio-economic effects, using existing OWFs as case studies is needed to provide a means to identify and mitigate negative effects, and enhance positive effects for future developments. This approach would allow for changes in ecology, commercial fish and crustacean abundance and fishing activity within proximity to existing OWFs, pre and post-construction to be quantified to provide evidence to inform planning and MPA co-location designation decisions.

The time and resource constraints of a PhD study cannot approach all the questions identified (Table 2.2). To identify the existing evidence base, and so evidence gaps, in relation to effects of OWFs on species abundance and resulting effects on resource users, a systematic review and meta-analyses of existing data on the ecological and resource user effects of OWFs, MREIs and similar artificial structures was conducted. The aim of the systematic review, presented in the next chapter was to identify clear research priorities within the thesis and the implications of co-locating MPAs around OWFs. The systematic review takes a structured approach of identifying the evidence base for a specific question and allows a transparent method of displaying the evidence gaps that the thesis will approach, to provide original research on the implications of co-location of OWFs and MPAs. Meta-analyses were conducted on data that were shared by authors of existing studies to examine positive (increased abundance) and negative (decreased abundance) species effects from artificial structure deployment, to approach the question of species specific effects from presence of OWFs and related structures. Meta-analysis relies on variance and sample size within the data sets used to provide confidence measures. The confidence measures therefore also provide an indication of the requirement to conduct further assessment, or if sufficient data already exists to inform decision making.


Define and Design
Prepare, Collect and Analyse
Synthesis
Collate and analyse existing environmental monitoring data
Evidence Gap One (Environmental effects)
Conduct ecology fieldwork and analyse data
Case study selection
Development of research strategy
Draw cross case study findings and conclusions
Introduction
Identification of key evidence gaps
Identification of data sources and design of data collection protocol
Literature review
Systematic review
Collate and analyse fisheries surveillance data
Synthesise findings with policy goals
Conduct interviews and analyse results
Evidence Gap Two (Resource user effects)
Conclusions
1
2
3
Thesis Structure (chapters)
4
5
6
7

Chapter 3. Systematic review of current evidence

Can OWFs act as marine protected areas?

Chapter published as: Ashley M. C., Mangi S. C., Rodwell L. D., 2013. The potential of offshore wind farms to act as marine protected areas – a systematic review of current evidence. Marine Policy 45: 301-309

3.1 Introduction

The spatial extent of the OWF footprint combined with increases in hard substrata within offshore areas will inevitably lead to alterations of habitats and communities at a variety of spatial scales (Jensen et al. 2000, Peterson and Malm 2008). There are also inevitable consequences for economic activities utilising the marine environment including aggregates, shipping and fisheries sectors (Costanza et al. 1997; Gill 2005; Beaumont et al. 2007; Punt et al. 2009; Inger et al. 2009). Previous reviews have highlighted the potential environmental advantages and disadvantages from construction, operation and decommissioning of various marine renewable energy installations (MREIs) (Hiscock 2002; Gill 2005; Linley et al. 2007, 2008; Inger et al. 2009; Grecian et al. 2010; Wilson et al. 2010). Specifically these identify that these installations have the potential to act as de-facto marine protected areas (MPAs) by providing artificial reefs, fish aggregating devices and exclusion zones to destructive fishing activities therefore augmenting fisheries and benefiting coastal areas (Linley et al. 2007; Inger et al. 2009). Within these reviews such possibilities are largely theoretical, drawn from the findings of species behaviour, artificial reef and MPA studies. Assessments of environmental impacts of MREIs have also identified potential conflicts that management decisions will be required to address as well as benefits that will only be realised with consideration of the layout and design of MREI arrays (Wilson et al. 2010; Witt et al. 2012). A well-recorded evidence base relating to the effects of MREIs (and comparable artificial structures) on marine fauna and flora, habitats and resource users is currently lacking. As offshore wind and wave farms have been increasingly studied since existing reviews were conducted, this review aims to assess current knowledge using a replicable search strategy that can be added to as research develops.

A systematic literature search and review (Pullin and Stewart 2006) was conducted to identify the current knowledge base. Existing data on the effect of OWFs and artificial marine structures (that are structurally similar and deployed in similar environments to OWFs) on the abundance and diversity of marine flora and fauna were examined through meta-analysis. Meta-analysis utilised the metrics (species abundance), the sample size and variation present in the data from existing studies to determine an effect size (level of increase or decrease in abundance) from presence of the OWF (or related structure) on species abundance. Associated confidence levels were calculated for each effect size (dependent upon sample size and variance present in the data sets used). This analysis was used to provide empirical evidence of the effect of OWFs and similar MREIs on factors attributed to a successful MPA, as defined under the OSPAR convention. That is: "*An area within the (OSPAR) maritime area for which protective, conservation, restorative or precautionary measures, consistent with international law have been instituted for the purpose of protecting and conserving species, habitats, ecosystems or ecological processes of the marine environment.*" (OSPAR 2003). Research is required to assess the environmental and economic potential of marine renewable sites to be managed as successful MPAs and to identify specific knowledge gaps that may be preventing optimal management strategies. Ecologically driven marine protection in Europe under the EC Habitats Directive 1992 and EU Marine Strategy Framework Directive 2008 has created an urgent need to understand the effects of these structures on the natural environment and resource users. This knowledge, therefore, relates directly to planning and management under the EU Integrated Coastal Zone Management recommendation 2002, the Common Fisheries Policy (CFP) 2002 and CFP 2011 reforms. A potential clash in policies is apparent between the environmental legislation and agreements to reach carbon reductions and pursue renewable energy targets in the EU, of 20% electricity production from renewable courses alongside a 20% reduction in greenhouse gas emissions by 2020. The primary renewable energy resources, wind and wave power, require structures to be built in the marine environment with limited current knowledge of their impact on marine environments and subsequent impact on human activities that utilise European seas (Inger et al. 2009). Environmental scoping and environmental impact assessments (EIAs) have been required of existing OWFs, followed by monitoring programmes to examine proposed impacts. Monitoring for early UK OWFs has been criticised as not providing sufficient detail to identify trends in species responses. Separation of species community changes from natural variation and identification of effects of possible changes on resource users were not clear due to limitations in survey design, analyses and interpretation of results (Walker et al. 2009).

The objective of this systematic review was to assess the current evidence on the positive and negative effects of OWF sites on biodiversity, fish populations and associated fisheries in relation to the needs of an effective MPA. This is achieved through examination of evidence from scientific literature on the effect of existing OWFs and comparable artificial structures including artificial reefs, seawalls, shipwrecks, oil rigs and alternative MREIs, such as wave energy devices, on the abundance and diversity of marine species as well as the socio-economic effects on fishing as a principal anthropogenic activity utilising these resources. As few MREI sites have been present for long periods, alternative structures were included due to the similarity of materials and structures to both concrete and steel OWFs.

3.2 Methods

MREIs and artificial structures which occur at similar depths and water temperatures to existing and proposed OWFs in temperate seas (5 - 60 metres deep) were included from the available literature. The systematic review literature search and inclusion methodology developed by Pullin and Stewart (2006) was applied to enable future repetition of the same review process to assess developments in the environmental and socio-economic knowledge base of marine renewable energy. This is of benefit to this developing area of marine spatial planning as the methodology with which studies are selected for the review is recorded and can be easily reproduced at a later date. By answering specific questions and discussing available evidence the results from a range of scientific studies are intended to be easily viewed and interpreted by policy makers, site managers and the scientific community across disciplines.

3.2.1 Question formulation

Question formulation was an interactive process involving University of Plymouth and Plymouth Marine Laboratory personnel from coastal and marine policy, socio-economic and biodiversity research areas. Questions were presented for feedback from personnel to ensure they were of relevance and would benefit research and management in this topic. A broad principal question was established and subsequent secondary questions were identified that approached the central considerations of an MPA. The primary question agreed on was: *'Can offshore windfarms act as marine protected areas?'* This question was broken down into specific components in order to define exact criteria that existing studies had to contain in order to be included in the final review (Table 3.1).

In order to relate a structures effects to specific attributes of a successful no-take MPA, secondary questions were identified including: *How do artificial structures affect marine species abundance and diversity?*; *How do changes in abundance and diversity at artificial structures compare to locally occurring natural habitats*?; *Which species show the greatest effect*?; *Are commercially important species affected*?; and *What are the economic effects to resource users?*

Table 3.1. Components (1) and specific criteria (2) that studies returned by the search process were required to adhere to for inclusion in the review.

1. Question components	Intervention: *Management regime, policy or action*	Subject: *Topic or unit of study to which intervention is applied*	Comparator: *What is compared?*	Outcome: *Relevant objectives of the intervention that can be reliably measured*
2. Inclusion criteria for studies.	Deploying OWF or artificial structure.	Diversity and abundance of fauna.	- Before construction and after construction comparisons. - Comparison between artificial structure site and an unaffected control site	- Species abundance measures:(biomass, density,number individuals). - Species diversity measures: (species number)

3.2.2 Search strategy

The following databases were used for the literature search: JSTOR, ISI Web of Science and CSA Illumina including the ASFA fisheries database as well as search engines including Dogpile meta search engine, Google Scholar and Google. The COWRIE UK offshore wind farm database was also searched for completed environmental monitoring reports from existing European OWF arrays.

3.2.3 Search terms

Primary and secondary search terms were devised to incorporate both marine renewable energy developments and artificial structures that are constructed of similar materials and found in similar environments to OWF sites. Specific search terms were devised in order to retrieve all relevant literature from databases according to study selection criteria. Primary terms were selected to identify types of artificial structures while secondary terms were selected to relate to key topics or subjects. Primary search terms were; *offshore wind farm, renewable energy, artificial reef, oil rig, wreck, marina, seawall.* Secondary search terms were; *fish, crustacean, benthic, fishery*. The secondary search terms were intended to provide a broad scope to identify the maximum number of studies whilst the primary terms were searched to include any study with that term irrespective of the study topic or focus in order to retrieve the maximum number of studies initially. The same four secondary search terms were used with each primary search term.

Primary search terms were entered into the selected databases and search engines, and the resulting search results were pooled into an EndNote database created for each primary term. In the case of general search engines the first one hundred results were reviewed for relevance and inclusion in the relevant database. Once searches were complete and all references were contained in separate EndNote databases, the search facility within EndNote was used to search secondary terms for each primary term database. All results that contained both primary and secondary terms were then combined and saved as a new EndNote database and duplicates were removed.

3.2.4 Analysis

Analysis of each study recorded their findings regarding the effect of the structure on, 1) Benthic organism abundance; 2) Benthic organism diversity; 3) Fish abundance; 4) Fish diversity and 5) Fisheries catches and income. The details of the study site location and characteristics were also recorded within the review process.

Comparisons of before and after construction or inside and outside the area covered by the structure reported in the text of a study were interpreted as general increases or decreases in abundance. In these cases data were extracted if available, including mean values, sample sizes and variance data for either benthic abundance or diversity, fish abundance or diversity or individual species abundance for before and after or inside and outside comparisons therefore allowing meta – analysis to be carried out. If data had been collected but was not published authors were contacted to obtain original data. This enabled analysis of effect sizes as a result of deploying artificial structures on species abundance and species diversity.

3.2.5 *Study quality*

To account for rigour of the original observations studies were reviewed according to data quality criteria established by Stewart et al. (2005) and adapted from the methods by Khan et al. (2001). This process allowed data quality scores to be assigned, providing separate scores for a range of criteria assessing each individual study’s design, range of replication, objectivity and consideration of potential variables. The weighting was adapted from the Stewart et al. (2005) review of the effect of terrestrial wind farms on bird species abundance. Potential for bias due to the data collection / sampling strategy was considered the main factor that would affect data quality and this is reflected in the high scoring for this factor (Table 3.2).

Table 3.2. Scoring criteria used to assign study quality scores to each reviewed study.

Study Design	Site comparison: primary data collection (**40**) Site comparison: historical or secondary data (**30**) Site comparison: regional knowledge or results of other studies (**20**) Time series comparison: artificial structure only (**10**) Single sample from study site (**0**)
Comparator	Before and after construction data collection both at structure site and outside structure reference site (**3**) Before and after construction at study site (**2**) Inside structure site and outside reference site (**1**) No comparator (**0**)
Variation accounted for between sites	Region and depth comparable (**+1**) Historical species presence comparable (**+1**) Sediment prior to construction comparable (+**1**) Size of sample area comparable (+**1**) Survey design comparable (**+1**)
Potential contributing factors accounted for	Major contributing factor at either study site or reference site measured (**+1**) i.e. structural complexity, management measures, fishing effort, aggregate dredging effort.
Sampling strategy	Sampling repeated in time and space (**2**) Sampling repeated in time or space (**1**) Sampling not repeated (**0**)

3.2.6 Meta-analysis

Meta-analysis has become commonly used in ecology since its conception in medical reviews (Pullin and Stewart 2006; Arnqvist and Wooster 1995; Osenberg 1999). This review used random effects meta-analyses based on weighted mean differences to provide summary effect sizes with each dataset weighted to a measure of its importance using Hedges *d* calculated in the statistical package MetaWin (Rosenberg et al. 2000). This statistic used sample size and variance (standard deviation) relating to mean species abundance and diversity recorded by included studies. More weight was given to large studies with low variance and less weight was given to small studies with greater variance. The effect referred to is the increase or decrease in abundance or diversity of species as a result of deploying an MREI or artificial structure. Separate meta-analyses were run for data available on community matrices for fish abundance and fish diversity and for individual species abundance data extracted from included studies. All fish species were included in a separate analysis to all benthic species and similarly all crustaceans and all algae to provide separate pooled mean effect size values for each taxa as well as effect size values for species data from each individual study.

Data for mean abundance of each individual species pre and post-construction, or at impact and control locations within taxonomic distinctions (fish, benthic fauna, benthic flora, and crustacean species) were extracted directly from studies. If abundance data were not published, data were requested from authors using the contact details provided in publications. Requests explained the use and application the data were requested for and that no further use of the data would be made. The same process was followed for variance data, (as the meta-analysis model required standard deviation values, standard error values were converted to standard deviation values). Sample sizes were available for most studies but clarification was requested from authors if required. Data on mean species abundance, variance and related sample size within each taxonomic category were inputted into separate comparison groups. Comparison groups were either before or after construction samples (or impact / control groups). Random effects meta-analyses based on weighted mean differences was then calculated on the data collated across these groups for each species category.

Random effect models assume there is a distribution of effects that depend on study characteristics. This suited the variable nature of the study designs and artificial structures incorporated in this review. However random effect models will provide larger confidence intervals than the alternative, a fixed effect model which assumes there is a single, true underlying effect (Pullin and Stewart 2006). Hedges *d* was calculated using mean values for abundance and species diversity (number of species), sample size and standard deviation data extracted for both control and experimental groups. Control groups were taken from baseline (pre-development) data or reference site data that provided an example of pre-construction conditions for each study site. Hedges *d* is a modification of Hedges *g* which accounts for the effects of small sample sizes (Rosenberg et al. 2000; Hedges and Olkin 1985). Hedges *d* was selected as it combines the benefits of recognising unequal sampling variances in the experiment and control groups (also possible through Hedges *g*) with a correction for a tendency of Hedges *g* to be slightly biased when sample sizes are small (Rosenberg et al. 2000).

3 Results

3.3.1 Search process

The EndNote database constructed from search results obtained in April 2011 for each primary search term contained a total of 16208 references. Following the systematic removal of duplicates, search for secondary terms in Endnote, removal of irrelevant topics and study locations, review at title and abstract level according to inclusion criteria and finally review at full text level 27 peer reviewed studies and four completed environmental monitoring reports met full inclusion criteria for inclusion in the final review (Fig. 3.1). The small number of studies for inclusion (in the final review) in relation to the large number of initial references was due to the systematic nature of the search process. Initial searches with primary search terms were intentionally broad to include the maximum possible number of relevant references. As different search engines returned similar references the removal of duplicates substantially reduced the number of references. The search terms also provided a large number of irrelevant topics, in particular returning many engineering related studies given the early stage of development of marine renewable energy technologies. Review at full text level identified many references amongst those removed that did not contain before or after comparisons, or inside (impact) and outside (control) comparisons.

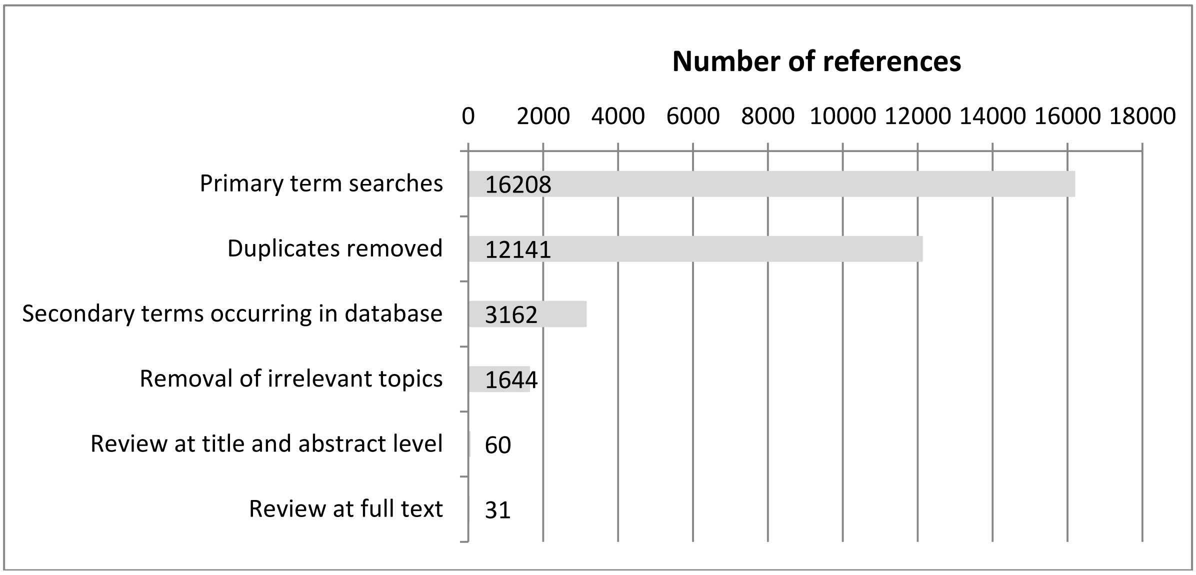


Figure 3.1: Number of references returned following initial search terms to final full text analysis.

3.3.2 Study characteristics

The final 31 studies were mapped according to site location and types of structure (MREI or other artificial structure) (Fig. 3.2). Studies were predominantly grouped in the North East Atlantic, North Sea and Baltic Sea regions (11 references) and the Mediterranean and Algarve sea regions (12 references). Other studies included North American coastal sites (four references including three references with study sites on the Pacific coast and one study on the Atlantic coast). Relevant studies of MREIs have only been carried out in the Baltic Sea and North Sea.

Figure 3.2: Locations of the final 31 studies returned by the search and review process. In certain instances more than one study utilised the same artificial structure or renewable energy site. Black crosses represent MREIs and black diamonds represent other artificial reef sites.

The study site characteristics of the 31 studies and the key findings of each study were recorded based on site characteristics (Table 3.3), and findings (Table 3.4). Only six peer reviewed studies compare fish or benthic communities at renewable energy sites with locally occurring natural sediment sites, with three at OWFs and three at wave farm sites. Presently artificial reef sites provide the most significant information relating to potential communities occurring within OWF sites. It is important to consider that although care has been taken to select sites that occur within similar depth, substratum and latitudes to present and future OWF developments in European and North American waters, the objectives of construction are potentially very different. Artificial reef sites may be designed with specific purpose such as habitat rehabilitation, fisheries mitigation or coastal defence, therefore, influencing the effect they may have on fish and benthic communities. However due to the limited studies on OWFs and MREIs, the inclusion of artificial reefs provides the best indication of likely effects and offers a means of comparison between the types of structure to test the predictions of earlier reviews. Three of the artificial reef sites included (two in Sweden and one in the UK) were constructed to replicate conditions within MREI sites. The studies used variable sampling methodologies to examine a range of species from benthic infauna (Wilhelmsson and Malm 2008; Langhamer 2010) to large mobile predators (Hunter and Sayer 2009; Santos et al. 2005). Assessments of fish populations were most common across all structures. The two most common sampling methodologies used were visual transects utilising scuba divers or experimental fishing using set gill nets (Wilhelmsson et al. 2006; Hunter and Sayer 2009; Santos et al. 2005).

Table 3.3 Structural and environmental characteristics of the studied sites included in this review.

Structure	Number of studies	Age of structure at time of study	Construction materials	Depth of structure
Offshore wind farms	7	1-2 years	Steel	3 - 10m
Offshore wave farms	3	1-2 years	Concrete bases	25m
Shipwrecks	2	1-54 years	Steel	4.2 - 20m
Artificial reefs	19	1-14 years	Concrete, tile and rubble	9 - 35m

3.3.3 Study quality

Study sample sizes were low although they varied from 3 to 21 replicates. The rigour of observations was variable with data quality scores ranging from 22 to 50 out of a possible data quality score of 51(Table 3.4). All studies were based on repeated observations at artificial structure sites and comparison sites that consisted of data sets collected before construction or at locally occurring natural sites comparable to the prior state of the site containing the structure. Effect size calculations were based on the mean, sample size and variance values present in these original data sets.

3.3.4 Findings of studies

Findings of studies are summarised in Table 3.4. The results of meta analyses that combined data on abundance and diversity of fish, crustaceans, benthos and algae species are also provided to support summarised findings (Figure 3.3). It is important however to interpret these with caution as they are only from individual studies that provided mean, variance and sample size data therefore creating a further reduced evidence base. The statistic (Hedges' *d*) refers to the positive (increase) or negative (decrease) effect of artificial structures on the relevant taxon.

Table 3.4. Findings of studies within this review on the ecological and socio-economic effects of marine artificial structures + represents an increase, – a decrease, +/- stands for no noticeable effect. Y = yes N = no. Data quality scores derived from the categories in Table 3.2 Blank cells represent this factor not being studied or no data presented in that study.

Reference	Location	Structure	Material	Benthic Biomass	Benthic Diversity	Fish Biomass	Fish Diversity	Represent Natural Fauna	Socio economic benefits	Data quality score
Andersson, Ohman 2010	Utgrunden, Sweden	Offshore Wind Farm (OWF)	steel	mollusc + algae -	species composition changes	+	+	N		48
Wilhelmsson, Malm et al 2006	Yttre Stengrund and Utgrunden, Sweden	OWF	steel	mollusc + algae -	-	+	-	N		47
Wilhelmsson and Malm 2008	Yttre Stengrund and Utgrunden, Sweden	OWF	steel	+	-	-	-	N		47
Npower 2005 (CMACS)	North Hoyle, UK	OWF	steel	+/-	+/-	+/-	+/-	Y		50
Vattenfall 2006	Kentish Flats, UK	OWF	steel	+	species composition changes	+/-	+/-	N		50
Eon Renewable 2005	Scroby Sands, UK	OWF	steel	-	+/-	+/-	+/-	Y		50
Vattenfall, Dong Energy 2006	Horns Rev and Nysted, Denmark	OWF	steel	+	species composition changes	+/-	+/-	N		50
Langhamer 2010	Lysekil, Sweden	Offshore Wave Farm	concrete	-	+			N		48
Langhamer and Wilhelmsson 2009	Lysekil, Sweden	Offshore Wave Farm	concrete	+	+	+	+	N		48
Langhamer et al 2009	Lysekil, Sweden	Offshore Wave Farm	concrete	+	+	+	+	N		48
Andersson, Berggren et al 2009	Gasevik, Sweden	Test site: 6 steel and 6 concrete pilings	steel and concrete	+	+	+	+	N		48
Wilhelmsson, Yahya et al 2006	Langholmen, Sweden	Test site: pvc pipe with concrete and tile	P.V.C., concrete and tiles	+	+	+	+/-	N		49
Hiscock et al 2010	Whitsand Bay, UK	Shipwreck	steel		+	+		N		37
Diamant et al 1986	Habonim, Israel	Shipwreck	steel			+	+	Y		46

Reference	Location	Structure	Material	Benthic Biomass	Benthic Diversity	Fish Biomass	Fish Diversity	Represent Natural Fauna	Socio economic benefits	Data quality score
Hunter and Sayer 2009	Loch Linnhe, Scotland	Artificial Reef (AR)	concrete	+	+	+		Y - local reefs		49
Jenson and Collins 1994	Poole Bay, UK	AR	Tyre and concrete	+	+	+	+	Y- over time		49
Danna et al 1994	Castellmare, Sicily	AR	concrete			+	+	N		48
Edelist and Spanier 2009	Haifa, Israel	AR	steel with P.V.C. pipes			+	+	- regional species		48
Sinis et al 2000	Neos Marmaris, Greece	AR	cement, ceramic and tyres	+	+	+	species composition changes	N		50
Fabi 1994	Ancona, Adriatic	AR	concrete	+/-	+/-	+	+	Y - fish N - mollusc		48
Fabi et al 2002	Ancona, Adriatic	AR	concrete	-	-			N		48
Leitao et al 2008	Faro, Portugal	AR	concrete and boulders			+	+	N		48
Leitao et al 2009	Faro, Portugal	AR	concrete and boulders			+			+	27
Ramos et al 2006	Faro, Portugal	AR	concrete and boulders			+			+	22
Santos and Monteiro 1997	Faro and Olhao, Portugal	AR	concrete and boulders			+	+/-	Y		47
Santos and Monteiro 1998	Faro and Olhao, Portugal	AR	concrete and boulders			+	+	Y		47
Santos and Monteiro 2007	Faro and Olhao, Portugal	AR	concrete and boulders			+	+	Y		48
Foster et al 1994	Delaware Bay, USA	AR	concrete	+	+	+	+	N		33
Danner et al 1994	San Luis, California, USA	AR	concrete	+	-	+		Y		49
Jessee et al 1985	San Onofre, California, USA	AR	rock boulders			+	+/-	Y		49
Reed et al 2006	San Clemente, California, USA	AR	rock	+	+	+	+/-	Y		49

Fish abundance showed the most consistent increase with construction of artificial structures, even in comparison to natural reefs. This was related to functional type of fish with species that are noted to prefer hard substratum and occupy benthic or mid water habitats such as Goldsinney wrasse (*Ctenolabrus rupestris,* greatest effect size from any single study d= 4.78 ± 1.93, 95% CI n=1; pooled studies d= 1.23 ± 1.27 95% CI n = 6), two spot gobies (*Gobius flavescens,* single study d= 3.68 ± 0.67, 95% CI n=1; pooled studies d= 0.67 ± 4.63 95% CI n= 3) and reef associated sea breams (*Diplodus spp*.) [34-36] displaying the greatest positive effect sizes or increased abundance post deployment although large CIs in the pooled meta-analyses reveal a current lack of significant evidence to support conclusions. Although increases in fish biomass were noted across studies, diversity of species did not increase to such a great extent with the predominant observable trend being only a small increase. This was attributed to a decrease or no observed effect on the abundance of soft sediment species such as sand goby (*Pomatoschistus spp*. single study; d= -1.02 ± 0.28, 95% CI n=1; pooled studies: d= -0.05 ± 1.75 95% CI n=3) and flatfishes (*Pleuronectidae* d= -0.71 ± 0.33, 95% CI n=1; pooled studies: d= -0.06 ± 3.31 n=2) and the dominance of a minority of reef associated species colonising the new structures. Although colonising species were recorded as occurring in the region they were often not present or only occurred in small numbers in the surrounding habitat. Overall fish abundance and diversity taken from studies which provided overall mean, variance and sample size data displayed positive effect sizes (abundance d = 0.73 ± 0.44, 95% CI, n=11 diversity d = 0.57 ± 0.53, 95% CI n=7). These effects were heterogeneous as a p value of greater than p = 1.0 was required to suggest homogeneity (abundance Q = 70.05; *d.f.* = 39; p = 0.008. Diversity Q = 49.78; d.f. = 31; p = 0.019) suggesting that the effects of artificial structures on fish abundance and diversity varied amongst sites.

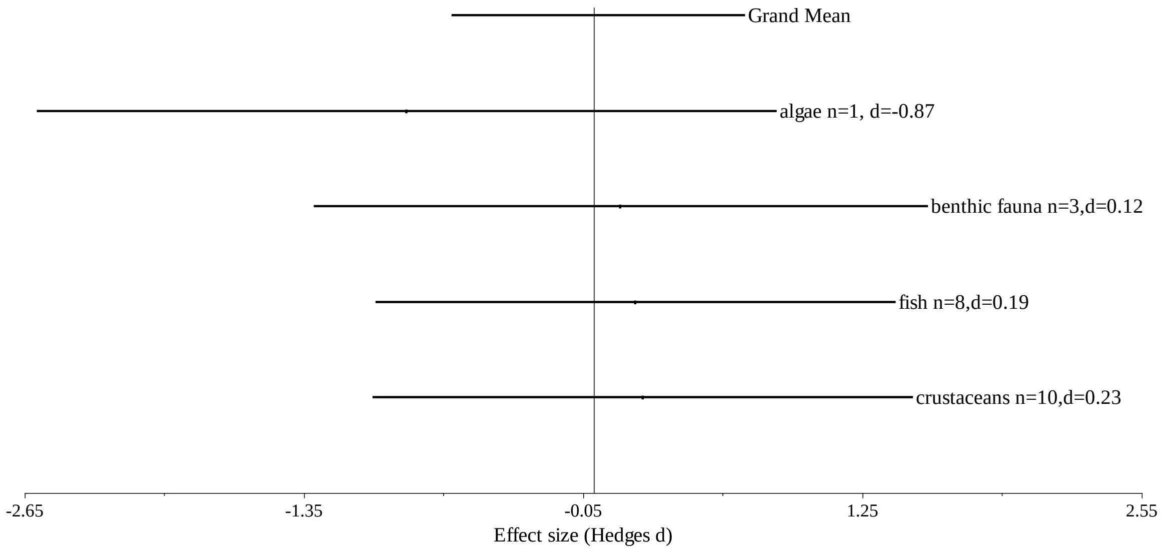


Figure 3.3: Plot of effect size (Hedges *d*) for species abundance data grouped in taxon (fish, mobile crustacea, benthic epifauna, infauna and algae). Vertical dash marks effect size and horizontal lines display the variance. Grand mean refers to the mean effect size for all groups combined. Positive effect sizes represent an increase in abundance post deployment of structures or in comparison to natural controls while negative effect sizes represent decreases in abundance, n= the number of individual studies pooled to determine each taxons mean effect size in the meta analysis.

Benthic fauna showed a small increase in biomass for pooled data (d = 0.12 ± 0.53, 95% CI n=3) although the high CI values reveal limited significance and again a lack of available data. As with fish abundance specific species dominated, especially at renewable energy structures. Species that were able to settle on the new hard substratum surfaces such as mussels (*Mytilus trosullus, d*= 0.56 ± 0.32, 95% CI n=1, no further studies for pooled data available) and barnacles (*Balanus improvis, d* = 0.89 ± 0.34, 95% CI n=1) display increases in abundance whilst, as with fish species certain sand and soft sediment associated species decrease in abundance or display no effect. Common starfish (*Asterias rubens)* were noted to dominate the sea bed habitats immediately surrounding turbines in post-construction environmental monitoring at two UK OWF sites (Wursig et al. 2000; RWE Npower 2006). This appears to lead to little change in diversity in terms of number of species present although in fact the actual species, or community observed may change considerably.

Motile crustaceans show one of the largest benefits from artificial structures and MREIs in particular with dramatic increases in abundance noted for brown crab in one study and a general increase seen across all studies (*Cancer pagarus* d= 3.73 ± 0.26 n=1; pooled studies: d= 0.99, ± 1.06, 95% CI n=9) and brown shrimp (*Crangon crangon* d= 4.75 ± 1.18 n=1). For these species increases in abundance appear to be linked to the increased availability of food resources and in the case of *C. pagarus* increased opportunities for shelter (Hunter and Sayer 2006; Jessee et al. 1985). Algae species appear to display the opposite effect with a large decrease at artificial structures at MREIs in comparison with surrounding natural habitat (d= -0.87 ± 0.77 95% CI n=1). The data on algae species abundance changes were collected at an artificial structure site where mussel and barnacle species dominated species communities on the steel and concrete pilings, possibly reducing available surface for algae species to colonise (Anderson et al. 2009). Many studies focused on epibenthic fauna and fish, reducing the data available to just one study on algae species abundance.

Overall, although artificial structures are providing a desired reef effect in that biomass of fish, crustacean and benthic species are increasing, the naturally occurring community has been altered. In their first years of deployment sites are shown to provide habitat for a large biomass of a limited numbers of species. Complex concrete or boulder artificial reefs display greater similarity to natural reefs, especially over time but the steel structures including shipwrecks and MREIs (in particular OWFs) host different communities to surrounding natural hard or soft substratums. However, communities adjacent to artificial structure sites increase in similarity to naturally occurring communities within short distances of the structure (Langhamer 2010).

Although communities on concrete or boulder structures appear to increase in similarity compared with natural communities over time, evidence from studies of long standing steel structures suggests they may support unusual communities even over the long term (Wilhelmsson and Malm 2008). Three studies identified alien and even invasive species occurring on structures (one shipwreck and two OWF studies) (Hiscock et al. 2010; Andersson et al. 2009) suggesting caution should be applied in utilising these sites to obtain conservation objectives. The two studies examining the effect of an artificial reef on fishing activity displayed potential yields of target species at the artificial reef site being greater than surrounding reefs within two years of deployment (Leitao 2009) and that an artificial reef received consistent fishing effort and catches equal or greater than the surrounding fishing grounds (Ramos et al. 2006). The calculated value of landings from fishing effort at this reef site resulted in earnings above the national minimum wage (Ramos et al. 2006).

3.4. Discussion

In this study, literature search, study inclusion and meta-analyses strategies from a systematic review process were applied and existing evidence retrieved and analysed relating to the debate over the use and benefit of OWFs as MPAs. Specific functional group and species level effects resulting from deployment of artificial structures in the marine environment were identified and effects of site characteristics on these results were explored. The combination of these analyses are aimed at advising policy makers and researchers about the current knowledge relating to the subject of offshore wind farm effects on the marine fauna, flora and habitats. Ultimately this process is intended to aid management decisions and highlight areas for future research regarding co-location of OWFs and MPAs.

Previous reviews note that the increase in hard substratum associated with OWF and other MREIs will provide additional habitat for fish and potential increase in fish populations (Inger et al. 2009; Linley et al. 2007). If fishing activity is restricted through the impracticality of using certain gears in OWFs or even official restriction through no-take zones, the increasing populations may ultimately result in a spillover effect into neighbouring fishing areas such as that reported by McClanahan and Mangi (2000). Results of existing studies assessing fish occurrence at renewables sites reveal the extent of this relationship to appear species specific with benthic and nekto-benthic species that favour hard substrata displaying the largest increases at sites (Wilhelmsson et al. 2006a, 2006b; Andersson and Ohman 2009; Hunter and Sayer 2009) and positive effect sizes in the meta-analyses. In contrast, soft sediment associated flatfish (*Pleuronectidae sp*.) and sand goby (*Pomatoschistus spp*.) display either no change in abundance or decreased occurrence (Wilhelmsson et al. 2006a, 2006b; Langhamer and Wilhelmsson 2009) and negative effect sizes in the meta-analyses.

The current evidence for renewable energy structures suggests colonisation by hard substrata associated species that are of low commercial value and display high site fidelity such as wrasse and gobies (Wilhelmsson et al. 2006a; Andersson and Ohman 2009). It is only in studies of artificial reefs deployed in areas with commercially valued reef fish and designed specifically for fisheries or habitat mitigation that benefits to commercial fish populations have been demonstrated (Santos et al. 2005; Ramos et al. 2006; Santos and Monteiro 2007).

Small positive effect sizes and increased occurrence of certain commercial species were apparent at renewable energy sites including occurrence of solitary individual juvenile cod (*Gadus morhua*) (Wilhelmsson et al. 2006a; Langhamer and Wilhelmsson 2009). At a steel shipwreck site in south west UK and an artificial reef site designed to mimic OWF scour protection in western Scotland schooling gadoids, including the commercially fished species *Pollachius pollachius* showed increased occurrence at the sites (Hunter and Sayer 2009; Hiscock et al. 2010). Meanwhile the large increases in edible crab numbers (*C.pagarus)* at a renewable energy site that deployed large concrete bases with added holes (Langhamer and Wilhelmsson 2009) suggests there may be potential for increasing stocks of commercial species. Detailed monitoring using standardised techniques over multiple seasons and at multiple sites is required to investigate these potential effects as current evidence is based on a very limited number of studies, reducing confidence available in the results of meta-analyses. Currently the most significant evidence is concentrated on sites within a very small area of the North and Baltic seas.

The dominance of certain benthic species, especially barnacles and mussels at renewable energy sites and the decrease in certain soft sediment associated species and algae has important implications for both ecosystems and the environmental services and economic activities they support (Beaumont et al. 2007; Linley et al. 2008). This change in community structure would appear to deserve further assessment both in extended time series studies of present sites and comparison with assessments of unstudied sites. Persistent trends could then be identified as well as the potential cumulative effects once greater numbers of sites covering greater spatial scales are constructed. As Wilhelmsson and Malm (2008) note these communities have persisted over the initial years of an OWFs existence and have similarities to bridge piling communities in the same regions that have persisted over even greater periods (Qvarfordt et al. 2006; Wilhelmsson and Malm 2008). This suggests that unlike previously studied artificial reefs, constructed of concrete or natural rock that appear to display similarity to natural substratum communities over time (Reed et al. 2006; Hunter and Sayer 2009). OWF pilings may always support distinct species assemblages. Without continued monitoring knowledge of the persistence of these distinct communities will not be available. Therefore the potential cumulative effect of OWFs at the present scale of development, involving many thousands of turbines is not yet understood. It is worth noting that artificial reefs and OWFs differ in a variety of ways. For example, the electrical cables running through OWFs produce both electrical and magnetic fields. The electrical and magnetic field (EMF) sensitivity of a number of marine organisms has been proven including elasmobranchs (Kalmijn 1982). Gill et al. (2009) have displayed responses from EMF sensitive benthic elasmobranchs to the presence of sub-sea electricity cables of the type used in OWF arrays. The initial fieldwork utilised a mesocosm to replicate conditions within an OWF array and further research is necessary to better understand species effects at the scale of present and planned OWF developments (Gill et al. 2009; Normandeau 2011).

3.4.1. Summary: The potential of OWFs to act as MPAs

The current evidence base to inform planning decisions regarding utilising OWFs as MPAs is lacking in part because of the limited time in which the structures have been present in the marine environment. Studies have been limited to specific sites and have not been continued beyond the initial one to two years after deployment, limiting the availability of significant results in the evidence base. The developing evidence however suggests caution should be used in designating OWF sites as MPAs if designation is based on the ecosystem approach. Firstly the assemblages occurring on structures are not necessarily providing significant examples of important naturally occurring habitats and secondly, unusual alien or invasive species have already been identified at three separate sites (Kjae et al. 2006; Hiscock et al. 2010; Wilhelmsson and Malm 2008). Without further monitoring the extent and potential for structures to provide suitable habitat for alien or invasive species to colonise and spread will not be known and detrimental effects to existing habitats will not be possible to forecast.

Benefits to co-location of OWFs and MPAs are identified from studies in this review. Significantly there was found to be an increased abundance of an economically important species, brown crab (*Cancer Pagarus*) (Langhamer and Wilhelmsson 2009). Although limited, evidence was also found for increased occurrence of fish such as commercial gadoids, Pollock (*P. Pollochius*) and cod (*G. morhua*) that support both commercial and recreational fishing (Hunter and Sayer 2009; Langhamer and Wilhelmsson 2009). Further knowledge is required to understand the extent of the association of these species with OWFs and the benefit any association may have on the resource and associated local fishing activities. Extended monitoring may establish if OWFs provide the same fisheries enhancement properties as purposely designed reefs such as Faro and Olhao artificial reefs in southern Portugal (Ramos et al. 2006; Santos and Monteiro 1997, 1998, 2007; Leitao et al. 2008, 2009). To achieve this, both well-replicated and long-term studies of fish occurrence within OWF sites appear necessary, along with assessment of the duration of residence of key species and the range species travel from the site. Detailed assessments of benefits and disadvantages experienced by commercial and recreational fisherman, including experience of spill-over in areas containing existing OWFs are also required.

Across Europe and in the UK in particular, OWF development is increasing at a rapid pace and going side by side with the development of increased environmental protection in the form of designated MPAs. This will decrease the grounds available to fishermen and displace fishing effort into smaller areas, increasing impacts on the unprotected or undeveloped areas (Inger et al. 2009; Kaiser et al. 2000). Potentially this could increase cumulative environmental impacts due to both MREI construction in closed areas and increased fishing effort in open areas as opposed to closure of a previously fished area with no construction activity present (Hiddink et al. 2006). Both social and economic consequences are implicated by reduction in fishing potential as fishing provides not only traditional employment but upholds a cultural identity and sense of heritage that relates to the generation of tourist interest in many OWF development areas (Williams 2008; Nadel Klein 2000; Urquhart et al. 2011).

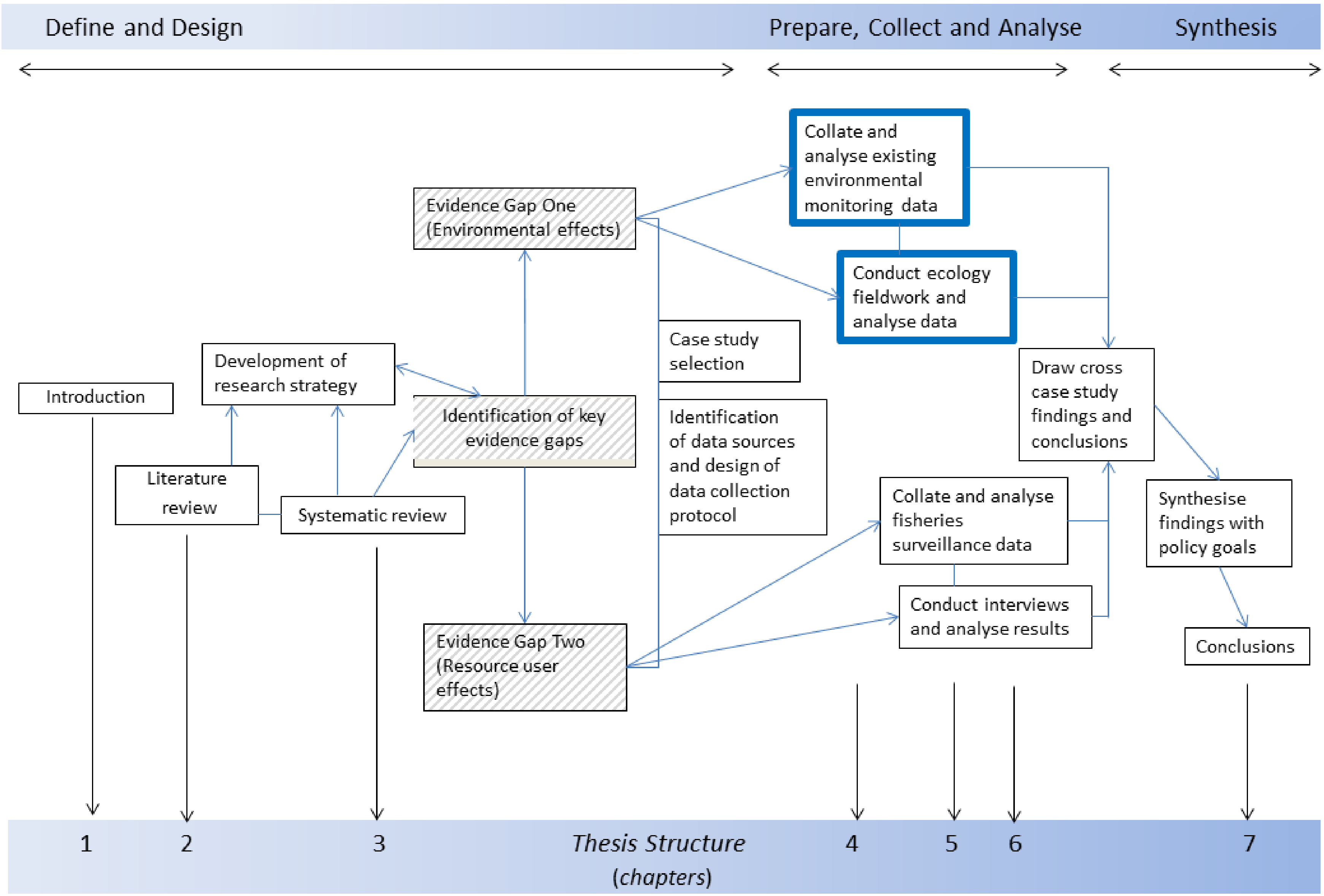
As current designs of mobile commercial fishing gears are not practical to use in the confined space of an OWF, existing sites may be acting as de-facto MPAs therefore making full MPA designation a simple practical step. The reduction of fishing activity using towed gears will decrease disturbance of benthic communities and promote recovery of soft sediment communities (Kaiser et al. 2006). However, the potential impact on surrounding grounds from displaced fishing activity has not been assessed. Only two studies were retrieved that approached socio-economic effects on fisheries and these looked at potential fishery yields and calculated income from fishing activity at an artificial structure site (Ramos et al. 2006; Leitao et al. 2009). This factor requires greater knowledge to understand cumulative impacts on a region’s habitats, and the resulting economic and social consequences in coastal areas following loss of grounds from renewable energy development and MPA designation. Evidence extracted and analysed in this review suggests that renewable energy structures are providing benefits to specific commercially important species in the form of food or shelter resources. There is at present limited available evidence of sites meeting ecological MPA requirements of preserving naturally occurring habitats.

Designating OWF as complete no take (no fishing) MPAs may maximise the benefit of increased occurrence of commercial species with limited extra impact on commercial fishing activities, especially if concrete or rock scour protection are utilised to best suit the species habitat requirements. In relation to various European countries' interests in developing MPAs, this provides a potential solution if little ecologically important habitat is available for protection in an area. Alternatively, incorporating OWFs as no take zones in a wider MPA that included ecologically important habitats and applied sustainable fisheries management measures would provide potential benefits. Benefits would only be realised however if effects of OWFs on species and ecosystems are better understood than at present and available evidence is assessed as a part of the environmental and economic aims of that MPA. As stated by Witt et al. (2012), in ecological terms there will be both winners and losers amongst habitats and species from MREI development which must be assessed as a net effect on a site by site basis when assessing ecological consequences of MRE installations. Development of the evidence base required to inform management decisions will also be greatly aided with increased transparency and availability of data from published reports and scientific studies, including publication of results (Witt et al. 2012).

Potential benefits from designation of OWF as MPAs are apparent to both conservation and commercial fisheries but require dedicated monitoring at multiple sites and over longer time scales to increase confidence in the trends identified, ideally utilising non-destructive field methodologies (Witt et al. 2012). It is also important that electrical and magnetic field effects on marine fauna are further understood (Gill et al. 2009; Normandeau et al. 2011), effects of different reef materials and designs utilised as scour protection are tested (Langhamer and Wilhelmsson 2009; Andersson et al. 2009) and piling and construction impacts are reduced through development of alternative engineering techniques such as utilising air bubble curtains around sites of mechanical piling (Wursig et al. 2000).

.○→● *3.4.2 Research required*

To approach these evidence gaps a multi-disciplinary study, focusing on the effect of OWFs on naturally occurring communities and relating this to changes in activity and resulting ecological and economic effects for a resource user was identified to be required. The following chapter addresses the ecological evidence gap through a case study of North Hoyle OWF, Irish Sea, UK. This case study will incorporate analyses of existing environmental monitoring data with analyses of species community data collected eight years post-construction, during fieldwork for this thesis. Effects on an existing resource user, through fishing activity and landings data were then analysed for the 5 year periods before and after construction of North Hoyle OWF and two further early UK OWFs in two different UK OWF development regions in the UK (Chapter 5). Interviews were also conducted with fishermen in each OWF development region (Chapter 6). Face to face interviews were used to understand the rationale behind any activity changes present and to gain information from a resource user that observes effects of OWFs on marine life and resulting social and economic effects on a daily basis.


Define and Design
Prepare, Collect and Analyse
Synthesis
Collate and analyse existing environmental monitoring data
Evidence Gap One (Environmental effects)
Conduct ecology fieldwork and analyse data
Case study selection
Development of research strategy
Draw cross case study findings and conclusions
Introduction
Identification of key evidence gaps
Identification of data sources and design of data collection protocol
Literature review
Systematic review
Collate and analyse fisheries surveillance data
Synthesise findings with policy goals
Conduct interviews and analyse results
Conclusions
Evidence Gap Two (Resource user effects)
1
2
3
Thesis Structure
(chapters)
4
5
6
7

Chapter 4. North Hoyle Case Study

Ecological effects of an OWF; introduction of new habitat changes marine communities.

4.1 Introduction

Evidence of effects of OWF sites on specific species and on marine communities is primarily reliant on short term studies with data collected up to two-three years post-construction (Walker et al. 2009). Specific fish, crustacean, echinoderm and bivalve species have displayed increases in abundance in association with both OWF pilings and offshore wave energy devices (Wilhelmsson et al. 2006a, 2006b; Wilhelmsson and Malm 2008; Andersson et al. 2009; Langhamer et al. 2009; Langhamer and Wilhelmsson 2009; Langhamer 2010; Degraer et al. 2010; Stenberg et al. 2011; Bergstrom et al. 2012; Reubens et al. 2013), suggesting an artificial reef effect relating to these structures (Wilhelmsson et al. 2006a; Langhamer and Wilhelmsson 2011; Degraer et al. 2010). More recent studies of fish abundance at Horns Rev OWF, Denmark show increases in abundance of reef associated and pelagic fish species in the OWF array seven years post-construction, while the flatfish species, dab (*Limanda limanda*) shows decreased abundance within the OWF (Stenberg et al. 2011).

Construction of OWFs is typically at shallow water sites less than 20m deep with predominantly mobile sedimentary sea beds. These conditions provide the best combination of water depth and distance from shore to facilitate construction and maintenance activities (Feld 2004; Linley et al. 2007). Shallow sandbanks support commercially important fish, crustacean and mollusc species at various life stages as well as species of conservation importance, such as slow growing elasmobranchs which are susceptible to fisheries impacts (Ellis et al. 2000; Kaiser et al. 2004). These habitats are currently recognised as requiring conservation under the EU Habitats Directive 1992, but knowledge of the effects of OWF presence on existing habitats and species currently relies heavily on limited environmental monitoring (Walker et al. 2009).

Within Europe environmental assessments are required as part of the licensing conditions for OWF developments (Gerdes et al. 2009). Substantial data on environmental conditions, benthic infauna and epifauna and fish communities are collected before and after construction, inside the site and outside as part of this process. Data for OWF monitoring (available during this study) were collected to assess broad scale construction effects. The lack of long term monitoring, control sites at greater distances from the impacted area and analysis of the interaction of each independent data set have been identified as considerable weaknesses in the monitoring design for UK OWFs (Walker et al. 2009).

Although evidence of reef effect, increasing abundance of hard substratum associated fishes and crustaceans has been identified (Wilhelmsson et al. 2006a; Langhamer and Wilhelmsson 2009; Reubens et al. 2013) the long term effects of OWFs on existing soft sediment communities and species of economic importance have received little attention. Potential benefits from increasing fish biomass through *de-facto* no take zones due to the restriction of mobile fishing gears are identified in existing reviews. Environmental disadvantages include the disturbance of sediment and underwater noise from construction activities (Hiscock 2002; Gill 2005; Linley et al. 2007, 2008; Inger et al. 2009; Wilson et al. 2010).

4.1.1 Review of findings of environmental monitoring reports related to FEPA license requirements at North Hoyle OWF.

The initial EIA environmental statements for North Hoyle OWF identified attraction of fish species to OWF pilings (reef affect), amongst further site specific topics that environmental monitoring was required to examine (conducted in accordance with the FEPA license for North Hoyle OWF) (Innogy 2002, 2003). Environmental monitoring was conducted by Innogy / RWE npower and consisted of one single year of pre-construction, baseline sampling of sediment types, biotope mapping, benthic infauna, benthic epifauna and fish. Sampling was then repeated with data collection during a two week period (within August/September) on an annual basis during the construction year and three subsequent post-construction years. RWEnpower (2006) summarised analyses of the data on sediment, biotopes, infauna, epifauna and fish species and discussed changes between pre and post-construction samples.

Changes were observed in sediment distribution, benthic fauna communities and fish species occurrence between pre and post-construction samples within the OWF array, and at sites to the south and east. Reports concluded changes were due to natural variation and were unrelated to the OWF development as they also occurred outside the North Hoyle OWF site (RWEnpower 2006). Results for the environmental monitoring conducted at the North Hoyle case study site are summarised below in relation to the original predictions raised in the Environmental Statement (Innogy 2002) (Table 4.1). The findings are summarised for each data set, sediment, infauna, epifauna and fish. As the monitoring related to FEPA license conditions was only required to identify the presence of broad-scale affects, the summaries below aim to identify if existing findings aid assessment of benefits of OWFs to MPA goals (recover or maintain habitats or species populations) (JNCC, 2013).Where weaknesses in the survey design and analyses are identified, alternative approaches are suggested to aid assessment of co-location potential. The further analyses and survey methods identified are taken forward in this chapter through re-analyses of the data collected for FEPA monitoring and follow up baited remote underwater video surveys, conducted for this study in 2011 (8 years post-construction).

Table 4.1 Review of existing monitoring conducted for FEPA license requirements at North Hoyle OWF.

Environmental data category	Issues raised in the Environmental Statement (EIA)	Findings (RWEnpower 2004,2005,2006)	Limitations in findings	MPA co-location benefits / disadvantages	Opportunities for further investigation / analyses
Sediment (day grab samples)	▪Scour around piles will remove finer sediments, leaving sediments that will be much coarser than previously. ▪This will effect the fauna able to colonise the sediment ▪Modelling of the distribution of fine sediement following construction showed principal areas of accumulation to be to the east and south of the OWF.	▪Increase in gravelly sediments adjacent to OWF pilings. ▪ Biotope present within the OWF array changed from sand and mixed sediment to gravelly sand. ▪ As sediments are highly mobile and heterogenous in the region reports concluded that: '*no trend present that would suggets that wind farm construction, cable burial or adjustment of hydrodynamic forces due to the presence of the piles in the seabed were responsible for changes in sediment characteristics at each site.*'	▪Statistical analyses were not presented in the available reports. Despite data being available for OWF and control locations and before and after construction (BACI). ▪Survey design, with a limited number of sample sites within locations, particularly within the OWF array and in control sites at varying distances from the array limit confidence in observed findings. ▪ Limited timescale with only 1 years baseline and 2-3 years post construction is not sufficient to identify significant effects on sediment characteristics (Walker et al., 2009).	▪ Limited confidence in findings and lack of analyses of the interaction of sediment and infauna ▪ Changes in sediment grain size in the OWF array are not discussed in relation to changes in samples from outside the array, or at sites at graduating distances from area of predicted impact. ▪ Evidence provided by current monitoring limits assessment of the potential benefits from co-location of OWFs within MPAs.	**Further analyses:** ▪ Statistical analyses of changes in grain size between the array and near and far-field controls, comparing baseline data and each subsequent years data set. **Changes to survey design: -** ▪ Increasing sample size within locations to investigate, i) near pile effects, ii) effects within the footprint of the OWF array and, iii) effects at near and far field distances from the array would benefit separation of effects of development from natural variation. ▪ Spatial survey designs could be adapted from assessment of pollution on benthic infauna in the North Sea oil and gas industry (Gray et al., 1990), or survey designs at renewable energy sites in comparable European seas (Langhamer 2010; Langhamer et al., 2009; Wilhelmsson and Malm 2008). ▪ Extending timescale of data collection to provide multiple year baseline data and over 5 years post construction data. ▪ Specific testing of cause and effect hypotheses of the effect of pilings on benthic fauna communities (Danheim et al., 2012).
Benthic infauna (day grab samples)	▪Minor and localised impacts would arise from construction and the loss of seabed habitat directly below piles. ▪ Recovery of communities from any damage is likely to be rapid, impacts will be negligible. ▪ Invertebrate communities will in no way be affected by sedimentation arising from the OWF construction. ▪Scour from the turbines will remove finer sediments leaving sediments more coarse than previous, which will affect the fauna able to colonise the sediment.	▪Abundances of specific invertebrate species were observed to change in the OWF following construction (in prticular increses in nematode species). ▪Infauna community changes were observed over post-construction samples in comparison with pre-construction samples. ▪Statistical analyses did not show these changes to be statistically significant. ▪As major trends in benthic invertebrate abundance and diversity were evident throughout the wind farm array and control sites, the changes were concluded to be the result of natural variation.	▪The limitations identified for sediment monitoring also limit the confidence in interpretation of benthic infauna monitoring findings. ▪The aim of the environmental monitoring programme was limited to identifying broad scale changes. ▪Distance from the development site was not considered in statistical analysis categories. ▪Species contributing to the changes in communities suggested by ordination plots between pre-construction baseline data and post -construction data sets were not investigated. ▪Interaction between infauna species (and community) data and sediment grain size data were not investigated (Walker et al., 2009).	▪The reported findings suggest benefits in relation to protecting, conserving or restoring species in accordance with MPA goals as increases in total abundance and species richness are reported. ▪However, it must be considered that this may be due to abundance of opportunistic species that may colonise a region following an impact (Gray et al., 1990).	**Further analyses: -** ▪ Whilst changing the survey design is not possible within this case study the same re-analysis of existing data, applying distance categories to statistical comparison of samples within the OWF and at graduating distances outside the OWF array is possible (although with the limitations imposed by the existing sample locations and survey design). ▪ The species contributing to dissimilarity between samples inside and outside the OWF between pre-construction samples and each year post-construction can also be investigated (for instance using the SIMPER routine) (Clarke 1993, Clarke and Warwick 1994). ▪ The interaction between sediment characteristics (mean grain size) and infauna communities at sample locations can also be investigated (for instance through the RELATE test in PRIMER) (Clarke and Warwick 1994, 2001). **Survey design: -** ▪ Changes in survey design as outlined for sediment data collection.

Environmental data category	Issues raised in EIA	Findings (RWEnpower 2004,2005,2006)	Limitations in findings	MPA co-location benefits / disadvantages	Opportunities for further investigation / analyses
Benthic epifauna (2m beam trawl)	▪ Recovery of communities from any damage related to construction is likely to be rapid, impacts will be negligible. ▪ Effect of the turbines and scour protection will be to replace the existing shallow *Venus* community with a hard substrate community that will increase species diversity. ▪ Communities on the turbine are expected to be similar to those observed on the meteorological mast and similar to those on Irish Sea gas rigs.	▪ Common starfish (*Asterias rubens*), brittle star species (*Ophiuroidea*) and flying crab (*Liocarcinus holsatus*) were the most abundant species across sites post construction. ▪ Cluster analysis separated OWF array and eastern sites from western and north-western sites post construction. ▪ Separation of species communities were related to perceived substratum at sample locations. ▪ Samples from within the array were reported to contain a mix of hard and soft substratum species. Samples to the south and east of the OWF array were reported to contain soft substratum species communities. ▪ Distribution and abundance of some of the most abundant species had changed noticeably post-construction. It was concluded that this was attributable to natural fluctuations within populations.	▪ Lack of multiple year baseline (pre-construction) samples prevents identification of pre-existing trends. ▪ Lack of statistical testing of the separation of communities limits identification of recovery trends. ▪ Interaction of these changes would benefit from interpretation in relation to observed changes in sediment and infauna (Walker et al., 2009). ▪ Challenging to interpret interactions due to sample locations for each data set being collected at different locations. • No background environmental conditions were collected (or discussed in the report). • Monitoring of colonisation of pilings was limited to video sampling and scrape-off sampling during a single post-construction survey.	▪ The monitoring programme concluded ; '*beam trawl surveys presently give no indication of any changes closely related to the development of the wind farm, with variations in species and communities occurring in control areas as well as in and adjacent to the wind farm, and appearing to be within the bounds of natural variation,*' (RWEnpower 2006). ▪ This suggests preservation of existing regional communiities, although confidence is limited due to weaknesses in survey design and analyses noted.	**Further analyses:** - ▪ Investigation of the separation apparent post-construction, between samples within the OWF array and south and eastern controls from the western controls. To investigate patterns in the cluster analyses and nMDS plots presented by RWEnpower (2006) control sites and OWF sites could be grouped according to east and west locations and similarity in communities tested through ANOSIM or PERMANOVA tests (Clarke 1993, Clarke and Warwick 1994, Anderson, 2001). Species contributing to dissimilarity between sample locations could be investigated through SIMPER (Clarke, 1993). **Survey design:** - ▪ Inclusion of further sample sites at a distance from the array would have provided the ability to test for effects on species communities at near and far field distances from the array (Gray et al., 1990). ▪ Collection and analyses of environmental variables in respect to data on epifauna communities would aid interpretation of effects of natural variation in reference to effects of the development.
Fish (2m beam trawl)	▪ The turbines of the NHOWF may operate as FAD and cause an accumulation of fish to occur from within the local area. ▪ Electro-sensitive species such as elasmobranchs may show avoidance or attraction responses to the NHOWF electrical cables. ▪ Impacts to fish from the underwater noise of the NHOWF are likely to initially follow startle and alarm response behaviour, then short term avoidance reactions, followed by habituation to the noise of operating turbines.	▪ Three species: sand goby *Pomatoschistus minutus*, lesser weaver fish *Echiichthys vipera* and dab *Limanda limanda* were reported as abundant across each survey year (in annual totals from all samples). ▪ Multivariate ordination showed similarity between post-construction fish communities in OWF samples and eastern control samples. Communities from samples at control sites to the north and west appeared similar to each other but separate from those in the OWF and eastern controls. ▪ Two commercially targeted flatfish species, plaice and sole, showed decreased abundance, most notably in the OWF array. ▪ No elasmobranchs were caught in the OWF array post construction.	• Weaknesses, limiting confidence in epifauna findings are relevant to fish data. • Large elasmobranch species are likely to escape the small, slow moving beam trawl used for sampling (Walker et al., 2009). • Sampling (2m beam trawl) was conducted at too great a distance from turbines to assess FAD affects. • Scuba diver surveys were only conducted once (one year post construction), preventing identification of long term habituation to noise, EMF and FAD affects. • Further statistical analyses of the post-construction seperation between communities, and analyses of species responsible for any dissimilarity present are required.	▪ The monitoring programme concluded; '*there is no evidence from the fish data to suggest that there has been any significant change in the species composition of the fish community of the area since the construction of the North Hoyle OWF.*' (RWEnpower, 2006). ▪ As for epifauna monitoring, this suggests preservation of existing communiities, although confidence is limited due to the weaknesses in survey design and analyses noted.	**Further analyses:-** ▪ As suggested for epifauna communities, control sites and OWF sites could be grouped according to east and west locations and similarity in communities tested through statistical routines such as; ANOSIM, PERMANOVA and SIMPER (Clarke 1993, Clarke and Warwick 1994, Anderson, 2001). **Survey design :-** ▪ Again improvements in spatial survey design as identified in review of epifauna monitoring. ▪ Greater assessment of piling footprint scale effects, to understand potential increases in presence and abundance of fish species are required. A variety of more appropriate techniques could be applied to achieve this, such as: using survey divers or remote visual survey techniques, trawl and netting methods (that would capture a greater proportion of the fish species present) and/or hydro-acoustic assessment. (Survey designs used by Wilhelmsson et al., 2006, Andersson and Ohman 2010 are applicable).

Summary: *Opportunities for addressing weaknesses across monitoring related to FEPA license conditions*

- Further analyses to examine change from pre-construction conditions would be beneficial. Investigating the significance of changes between years within sample locations and investigating changes in similarity or differences in communities (infauna, epifauna and fish) between sample sites inside the OWF array, and those at different locations outside would benefit interpretation of the extent of effects of OWF development or natural variation. Different location categories for analysis suggested by cluster analyses and nMDs plots in the monitoring programme results include: distance from the array and position; inshore, offshore and to the east and west of the OWF array.
- Data sets on sediment, infauna, epifauna and fish collected in relation to FEPA license requirements at North Hoyle OWF require further interpretation in relation to each other. Where possible these data sets could be analysed to assess interactions between different receptors (Walker et al. 2009).
- The monitoring conducted to meet FEPA license requirements at North Hoyle was only required to continue 2-3 years post-construction. The results of the monitoring programme suggested no major broad scale impacts had occurred and no further monitoring was required (RWE npower 2006; Walker et al. 2009). To address the potential benefits from co-location of OWFs within MPAs follow-up sampling, to examine species distribution and abundance, and community presence 8 years post-construction (and 5 years since the last monitoring samples) would be beneficial. This would provide the opportunity to identify if trends showing changes in sediment and species community distribution persisted, or a recovery to baseline conditions occurred throughout the study site. Such a study would still be limited by the lack of

extensive baseline data to identify what true pre-existing conditions and trends were at the study site.

- Extended baseline data and post-construction monitoring is required to separate development effects from natural variation. As leased areas for future round 2 and round 3 UK OWFs are already known, joined up approaches between stakeholders could be used to make extensive and costly pre-construction data collection feasible in the leased areas. Given the current marine planning systems in place and current designation of national MPA networks, developers, regulators, the Crown Estate, government environmental advisory groups such as; JNCC, EN, NRW, and environmental NGOs such as; RSPB, Wildlife Trusts, MCS and National Trust share an interest in developing the best available knowledge base on environmental effects of OWFs, especially as OWF developments extend to larger scales (Borja and Elliott 2013). Collaborative baseline monitoring of leased areas would benefit from survey designs that incorporated near field and far-field control sites. Future pre and post-construction monitoring would benefit if surveys examined effects at the scale of individual pilings and associated scour protection and surrounding sea bed (as well as monitoring effects at array scale and near and far-field controls sites).
- Walker et al. (2009) also identify the value of incorporating national monitoring programmes (e.g. UKMMAS), and co-ordinated regional assessments (possibly based around the Crown Estates Round 3 proposals for Zonal Assessment Plans) into monitoring regimes. The addition of such methods are recognised to give the potential to alter benthic monitoring requirements, to a programme of less frequent, but longer term monitoring, although some more frequent monitoring concentrating on the known near-field and colonisation impacts will still be required (Walker et al. 2009).

- Research requirements for near field and colonisation impacts at piling and scour protection footprint scales, identified Walker et al. (2009) and response of certain species such as elasmobranchs to construction and operation of OWF arrays requires cause and effect hypotheses driven studies (Danheim et al. 2012).

- The analyses methods applied to the environmental monitoring data related to FEPA license requirements at North Hoyle OWF utilise statistical analyses tests and routines available in PRIMER (Clarke 1993; Clarke and Warwick 1994, 2001). These had interpreted the data based on community similarity matrixes (Bray Curtis similarity matrix) where presence of species and abundances of species at each sample site is utilised to assess the similarity/dissimilarity of communities between different samples (expressed as the distance between samples). These are some of the most commonly applied measurements and techniques to express relationships in ecological data, further approaches and techniques have been developed to investigate the patterns observed in species community distribution. These include:

- *Trophic group analysis*: investigates differences in feeding mechanisms between assemblages (Roth and Wilson, 1998; Desrosiers et al. 2000,).
- *Biological traits analysis*: considers a range of biological traits expressed by organisms to assess how functioning varies between assemblages (Bremner et al. 2006; Tillin et al. 2006).
- *Functional analysis of community structure such as the guild approach*: considers main features of the species biology and the way in which they use a habitat, such a exploiting the same resources. (Nagelkerken and van der Velde, 2004; Elliott et al. 2007).

To address these weaknesses this chapter presents analyses of existing monitoring data collected in relation to FEPA license conditions. These data were collected and analysed in the original monitoring to address license conditions on identifying the presence of broad scale effects. To investigate the potential for MPAs to be co-located around OWFs, weaknesses in existing data collection and analyses to address this question are identified and opportunities for further analyses have been identified, which are addressed in this case study:

1) Changes in sediment mean grain size and benthic infauna data from sample sites within the OWF array, and at graduating distances from the array, are investigated for data collected annually before, during and after OWF construction.
2) Interactions between changes in sediment grain size and benthic infauna species and communities recorded at sample sites are investigated.
3) Changes in epifauna and fish communities are examined before, during and after construction for sample sites within the OWF array, and for control sites to the east and west. Statistical analyses examined the patterns observed from cluster analyses and ordination plots in post-construction samples (of differences between communities at sample sites within the OWF array and control sites to the south and east to control sites to the west).
4) The lack of long term monitoring at OWF developments beyond 2-3 years post-construction was addressed through baited remote underwater video surveys undertaken at North Hoyle OWF 8 years post-construction. These surveys collected original data on mobile epifauna and fish communities for this study. Multivariate community analyses were undertaken to examine if trends identified in mobile epifauna and fish communities in the first 3 years post-construction were present 8 years post-construction. Additional environmental variables were collected for sample sites that were lacking from the data collected in existing monitoring data, collected in relation to FEPA license requirements.

The interaction of mobile epifauna and fish species communities with environmental variables was tested to examine the role of environmental variables on changes in communities across sample sites, as well as the presence of the OWF (to address the weakness identified in the earlier monitoring surveys) (Walker et al. 2009).

5) Interactions between changes in sediment grain size, benthic infauna communities, epifauna communities and fish communities in relation to construction and operation of the OWF, and existing environmental and hydrographic conditions in Liverpool Bay are discussed. Results are discussed in relation to other similar studies and the potential benefit to MPA goals of co-locating OWFs within MPAs are summarised.

The chapter examines the hypothesis for environmental effects of an OWF, that: presence of an OWF will increase fauna diversity and abundance within OWF sites. (Null hypothesis – Presence of OWF will not change fauna diversity and abundance within OWF sites, i.e. no change will be seen from exiting baseline data and identified natural trends).

The key questions addressed are (1) Do fish and epifauna abundances increase in an OWF array over time? (2) Which species benefit from OWF presence and which do not? (3) What is the relevant impact of OWF presence on distribution of fish and epifauna species communities compared to environmental variables and infauna community structure?

It must be recognised that analysing these data sets to investigate finer scale effects on infauna, epifauna and fish populations needs to be interpreted cautiously (as the original survey design aimed to identify broad-scale effects). The follow up survey using BRUVs in 2011 is intended to provide a means of investigating if trends continue beyond the span of existing monitoring.

Five year before and after construction monitoring has been required at all OWF sites developed in UK waters. The analyses contained in this chapter of existing environmental monitoring data from North Hoyle OWF combined with analyses of follow up BRUV data collection 5 years later is intended to develop and test a methodology for investigating the longer term environmental effects of an OWF site. This chapter aims to use, test and evaluate a methodology to address issues identified with existing monitoring (Walker et al. 2009). The methods applied aim to be achievable within limited time and financial resources. The methodology is intended to be transferable to other OWF sites within the UK and Europe. The limitations of the use of secondary data are acknowledged but the financial and temporal constraints of collecting multiple long-term environmental and fauna data sets, at a variety of OWF sites within the data collection period of this study required secondary data to be used. This limits the experimental designs possible to consider fine scale environmental effects and interactions of construction and operation.

4.2 Materials and Methods

4.2.1 Study Site

Historical data for this study was analysed from a study site in the Eastern Irish Sea containing North Hoyle, a thirty turbine OWF constructed in 2003 covering 10 square kilometres, 6 kilometres offshore of Rhyl, North Wales, UK, 53° 25'N, 03° 27 W (Figure 4.1). The OWF turbines were 4 metres in diameter and pile driven into the bedrock underlying mobile sand, mud and gravel sediments. Stone scour protection with stones ranging from 10mm to 300mm was only placed around cable tie ins and the J tube (cable sheath) at the point cables passed into the sea bed beside each turbine (Ottensen Hansen 2005). Baseline data were collected during August and September 2001 and 2002.

Construction monitoring was conducted during August and September 2003, post-construction monitoring was carried out during August and September 2004, 2005 and 2006.

Surveys were conducted by the Centre for Marine and Coastal Studies (CMACS Ltd) on behalf of RWE npower to collect sediment for gravelometry data and benthic infauna, benthic epifauna and fish samples for abundance data. The data sets were collected for an environmental impact assessment which looked specifically for broad-scale environmental effects of construction of North Hoyle, the first OWF test site in the UK. Access to the data sets analysed in this chapter was kindly allowed by RWE npower and data sets were provided by CMACS Ltd.

Further mobile epifauna and fish surveys were conducted from 24th August to 29th September 2011. These aimed to investigate the abundance of mobile epifauna and fish species within the site and at control locations surrounding North Hoyle OWF 5 years after environmental monitoring was completed and 8 years post-construction.

4.2.2 Field Methods

All sampling, sediment and faunal data collection for existing environmental monitoring were carried out by CMACS Ltd. using the methodology detailed below and in their referenced reports. Data analyses and further field data collection in 2011 and analyses were carried out as a part of this study (Table 4.2).

Table 4.2. North Hoyle OWF environmental monitoring data sets and data sets collected by the author that were collated for analyses, * indicates the year of OWF construction.

	Environmental variables	Sediment	Infauna grab	Epifauna and fish trawl	Baited remote underwater video	Provider
2002		x	x	x		Innogy
2003*		x	x	x		RWEnpower
2004		x	x	x		RWEnpower
2005		x	x	x		RWEnpower
2006		x	x	x		RWEnpower
2011	x				x	Ashley,M

4.2.3 Sediment and infauna – existing environmental monitoring data

Surveys were conducted during September 2002 at 17 monitoring sites and again during September and October 2003, 2004, 2005 and 2006 at the same 17 monitoring sites and 3 additional sites adjacent to one of the monopiles in the North Hoyle OWF (Figure 4.1b). Details of the sampling methodologies can be found in existing environmental monitoring reports, Innogy (2003) and RWE Npower (2004, 2005, 2006). Sediment and infauna samples were collected using 0.1m² day grabs. Three replicate samples for fauna and one sediment sample were collected at each sample site. Sediment samples were screened through a series of mesh sizes from 9.5mm down to 63μm.

For infauna samples RWE Npower (2004, 2005, 2006) reports indicated sediments were methodically searched using forceps and a white enamel tray by the same CMACS Ltd. laboratory processor for each sample. Quality control was reported as being exerted by the chief taxonomist randomly checking one in every ten sorted samples. If sorting efficiency was found to be less than 95% then all ten of the samples are reported as being re-sorted by the original sorter (RWE Npower 2004, 2005, 2006). All organisms found were separated into major taxonomic groups (e.g. molluscs; worms; crustaceans; echinoderms; others) and preserved in 70% alcohol for later identification (RWE Npower 2004, 2005, 2006).

All the archived organisms from each sample were identified to species level where possible, in cases where this was not possible (e.g. juvenile and damaged specimens) genus or next higher taxa were recorded. All organisms were recorded quantitatively where possible but colonial forms (bryozoans, hydroids and sponges) were recorded on a presence/absence basis. Nomenclature followed the Ulster Museum and Marine Conservation Society species directory (Howson and Picton, 1997) (RWE Npower 2004, 2005, 2006).

Analyses within this study, of sediment and infauna data, used consultancy data from all samples except those from three sites adjacent to the cable route (7, 8 and 9) (Figure 4.1b). Although these sites were outside the OWF the effect of cable laying and operation would have possibly confounded results.

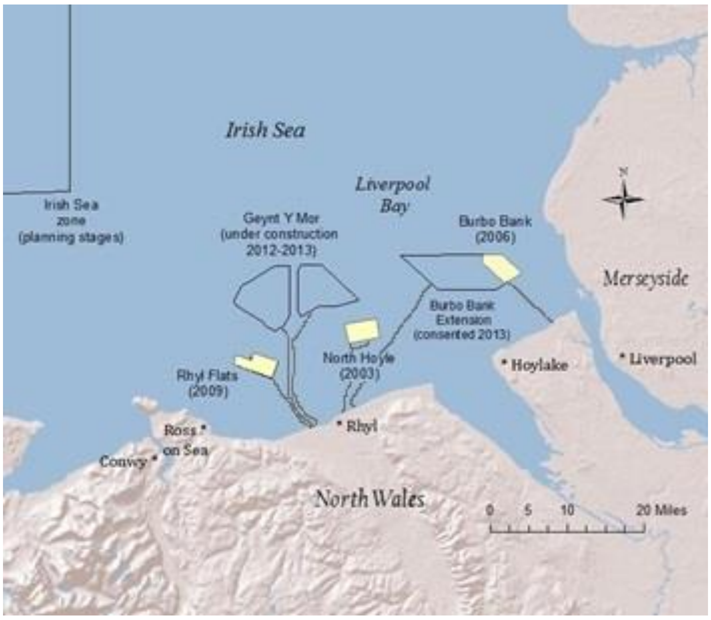


Fig 4.1 a) Map of the North Hoyle study site at the time of the study, including construction dates (in brackets) of surrounding OWFs.

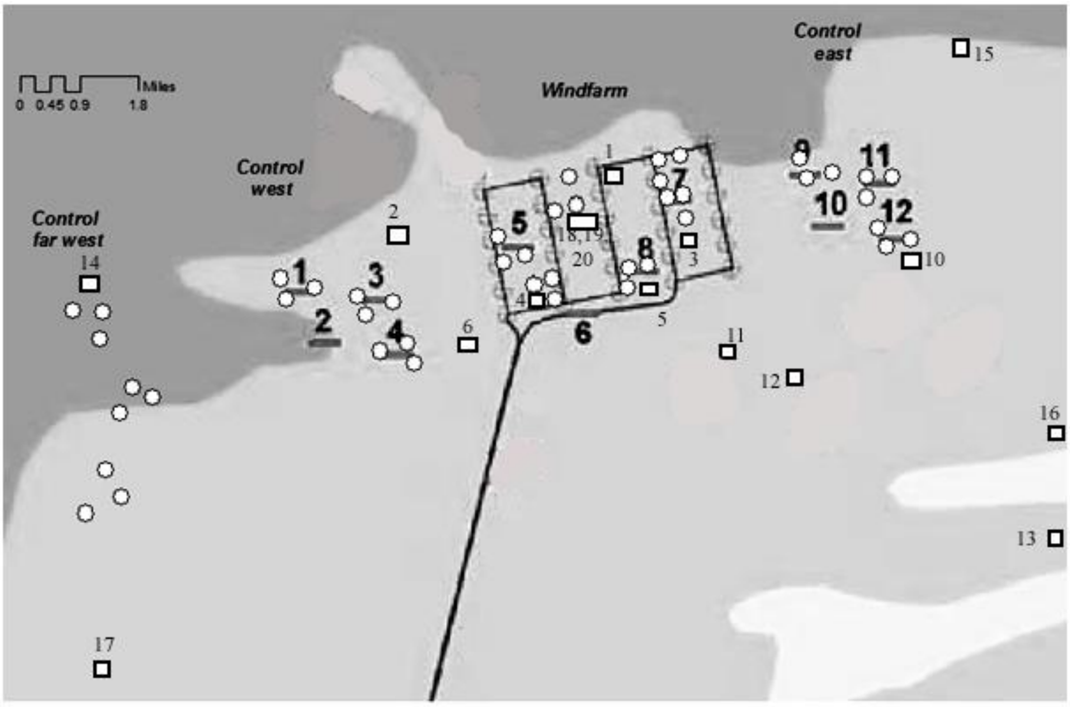


Fig 4.1 b)

Figure 4.1 a) Map of the North Hoyle study site including construction dates (in brackets) of surrounding OWFs, 4.1 b) Map displaying sample sites for 2001-2006 benthic infauna and sediment monitoring (white squares), benthic epifauna (dark grey lines) and sites for 2011 BRUV surveys, (white circles, with 2 cameras dropped 50 metres apart at each site marked by a circle).

4.2.4 Fish and epifauna – existing environmental monitoring data

Historical data provided by RWE npower and CMACS Ltd. on fish and epi-benthos had been collected in beam trawl surveys using a 2m beam trawl with a 4mm square mesh cod end. Trawls were carried out at 2 knots along a 300m track. Full methodologies are provided in the environmental monitoring reports of Innogy (2003) and RWE npower (2004, 2005, 2006).

Data were used from trawls carried out at 4 sites inside the array, 4 control sites within comparable depths to the east and 4 trawl sites to the west of the array (Figure 4.1b).

4.2.5 Fish and mobile epifauna – Baited Remote Underwater Video survey (2011)

Baited remote video camera (BRUV) surveys were conducted between 24th August and 14th September 2011 as a non-invasive method to investigate fish and mobile epifauna communities 8 years post-construction (Sheenhan et al. 2010). Two high definition video cameras lit by LED light sets were secured in underwater housings within aluminium frames (Panasonic HDC-SD40, Seapro housing). Bait boxes containing 100g of bait (mackerel) were then attached to the frame by 1m long poles and the apparatus were lowered to the sea bed by rope lines from the survey vessel Suveran II (8m catamaran, Rhyl) at each of the locations in Figure 4.1b.

The two baited remote video cameras (BRUVs) were left static on the sea bed for a minimum of thirty minutes, 50 metres apart at each survey site to provide two replicate samples. High visibility buoys attached to the line allowed survey personnel to retrieve the camera apparatus, as well as monitor their position whilst the vessel operators remained vigilant at all times of boat traffic and safety considerations.

The BRUV survey design utilised two wind farm survey locations (east and west OWF) and three control locations (east and west and far west control). There were nine survey sites in each location, clustered in groups of three with each group of three corresponding to a beam trawl survey tow site in the original environmental monitoring (Figure 4.1b). The two cameras were dropped 50 metres apart at each of the survey sites to provide replicate samples.

Individual sample sites have been located at 10 of the original 22 beam trawl locations from the existing monitoring programme, focusing on the beam trawl locations that lay along the same depth contours as those occurring in the OWF array (Fig 4.1b). Multiple control sites and multiple sampling sites within the OWF array were used, to reduce the chance of confusing effects due to natural spatial variability with effects due to presence of the OWF (Pelletier et al. 2008). Depths and general sediment type were also consistent between the OWF array sites and control sites, to reduce confounding effects that might be ascribed to environmental variability with effects due to the presence of the OWF (Garcia-Charton and Perez-Ruzafa 1999; Claudet et al. 2006). The additional samples from the far west control location were collected to provide samples with less likelihood of being influenced by possible effects of the OWF (as initial control sites were within two miles of the array).

In BRUV surveys the use of bait is recognised to have a confounding effect on the diversity and abundance of species present at the site that will be attracted to the camera (Harvey et al. 2007). As the objective was also to compare species presence and abundance to existing trawl data and identify if changes in species abundance and assemblages occurred over time, key mobile species were identified that were typical of shallow sandbank habitat in the Eastern Irish Sea. The selection of indicator species in relation to long term study of the recovery of Lyme Bay reefs following closure to mobile fishing gears was adapted in this process (Jackson et al. 2008). Key species included those that contributed to the *Pleuronectes platessa* - *Limanda limanda* assemblage that is representative of sandbank habitats in the study area (Ellis et al. 2000). Additional important commercial species occurring in the region and species with known sensitivity to electric and magnetic fields were also included to investigate presence of the OWF on these species. Key species included the fish species: *Pleauronectes platessa, Limanda limanda, Solea solea, Buglossidium luteum, Merlangius merlangus, Eutrigla gurnadus, Trigla lucerna, Callionymus lyra, Scyliorhinus Canicula, Scyliorhinus stellaris, Gadus morhua,* the crustaceans: *Cancer pagarus, Liocarcinus* *depurator, Liocrchinus holsatus, Pagarus Bernhardus* and the echinoderms, *Asterias rubens* and *Astropecten irregularis*.

Depth in metres (Furano Tzt14), water temperature in °C and salinity were recorded at the site of each BRUV sample (YSI instruments 6820).The influence of the Dee Estuary on nutrient availability, sediment distribution, particulate matter, prey resources and salinity was considered a potentially important influencing factor due to the estuary’s proximity to North Hoyle OWF. To account for this the distance of each camera sample site from the western mouth of the Dee estuary was calculated using the distance measure tool in ARC GIS 10. It was not possible to collect sediment samples or measurements of tidal flow at sample sites due to time and equipment constraints. As these measurements were acknowledged to be important environmental variables an approximate estimate of sediment type was visually determined from each sample video. A scale between 1 and 5 was used where 1 represented fine sand, 2, medium sand, 3, coarse sand, 4 sand and gravel and 5 sand and pebble, based on the classification scale of Buchanahan et al. (2004). The strength of the current was also estimated from visual observation of each sample video based on the rate of movement of particular matter on a scale of values 1 to 5. With 1 representing no or very little movement, 2 representing identifiable movement, 3 representing constant movement, 4 representing rapid constant movement and 5 representing very rapid movement.

4.2.6 Baited remote video camera - data collection

The BRUV survey provided 90 x 30 minute videos. In each video, species presence and abundance were quantified by counting maximum number of individuals of each species appearing in the field of view within 1:00 minute segments of video, starting at 5:00 minutes from the camera reaching the bottom until 30:00 minutes after this point. The delay provided time for sediment to settle and an olfactory trail to be established within the tidal stream. This technique provided 25:00 minutes of video to be analysed for each point. Mean species abundance was calculated from the 25, 1:00 minute segments for each sample. The maximum number of any one species observed in a single frame during each 1:00 minute segment was recorded, to account for the potential for individuals to move in and out of the field of view (Cappo et al. 2003; Cappo et al. 2004; Carr 2010; Zintzen et al. 2012). Visibility restrictions in many videos made distinguishing between flatfish species, brittle star species and goby species unreliable. Therefore, flatfish species were grouped under the family, Pleuronectidae (although as surveys were carried out late in the summer, plaice (*Pleuronectes platessa*) were likely to be seasonally rare). Brittle starfish species were grouped under the class, Ophiuroidea and species from the family Gobiidae were grouped under the genus, Pomatoschistus.

4.2.7 Comparing baited video and beam trawl data

Both beam trawl survey data and BRUV data provide mean species abundance and diversity for ten of the same sample sites. This provided data up to eight years post-construction for comparisons of mean abundance and diversity, between locations within the OWF array and control locations within naturally occurring habitat outside the array. Mean abundance for individual species were compared year by year between OWF array and control sites. Due to the different sampling methods re-analyses of 2001-2006 beam trawl surveys were conducted separately from analyses of the 2011 BRUV survey data. Results of analyses of 2011 data were interpreted and discussed in relation to patterns identified in results and analyses of existing monitoring data. For the analyses conducted as part of this study the beam trawl tow abundance data were averaged by the time for each of the tows to provide a catch per unit effort (CPUE) value of species abundance per one minute of trawling.

4.3 Data analysis

4.3.1 Benthic infauna – existing environmental monitoring data

Historical data from sediment and benthic infauna samples were analysed according to sample site location. Infauna data were analysed to compare sample sites within the OWF (n= 4 in 2002, n=7 2003-2006) and sample sites in control locations outside of the array (n=10) between years (2002, 2003, 2004, 2005 and 2006). Benthic infauna data were then analysed to examine the effect of distance from the OWF between years. Sample site locations were identified as inside the array (sample sites 1,3,4,5,18,19, 20), near to the array if within 2 kilometres (sample sites 2, 6 and 11), mid distance from the array if between 2 and 4 kilometres (sample sites 10 and 12), and far if over 4 kilometres from the array (sample sites 13,14,15,16,17). The original data collection conducted by RWE npower and CMACS Ltd recorded three replicate samples at each sample site. The mean values of these replicates were calculated and used for analyses.

To obtain an overview of the characteristics of infauna communities inside the OWF and those outside between 2001 and 2006 mean species richness, mean number of individual organisms and H' (loge) diversity were compared for locations inside and outside the OWF. Data were displayed in line plots and compared using the non-parametric Mann Whitney *U* test on square root transformed data.

The Primer 6 statistical analysis package was used for the following analysis. To examine changes in benthic infauna assemblages between years and inside and outside the North Hoyle OWF site, non-metric multidimensional scaling (nMDS) was undertaken from Bray-Curtis resemblance matrices calculated for each data set. Species abundance data sets were square root transformed to reduce the influence of the most abundant species. To test for the effect of location (inside and outside the OWF) and time (survey year) on infauna species assemblages, a PERMANOVA two way permutation test, based on Bray-Curtis similarity matrices on square root transformed data was performed (Gray et al. 1990; Clarke and Warwick 2001; Anderson 2001). One-way ANOSIM tests were conducted on the same data set to test for differences in species communities between locations (inside and outside the OWF) within each survey year.

Sediment mean grain size was recorded at the sites of benthic infauna samples between 2001 and 2006 inside and outside the OWF. As well as graphically representing mean grain size for sample locations within nMDS plots of species communities the RELATE test was performed in PRIMER 6. The RELATE test examined the correlation using Spearman rank between the similarities between samples in the biological Bray-Curtis resemblance matrix for species assemblages and the corresponding environment resemblance matrix for mean grain size from sediment samples.

To investigate which species contributed to Bray-Curtis dissimilarity between assemblages each year both inside and outside the OWF, the similarity percentage procedure SIMPER was used. The SIMPER procedures were calculated firstly to compare the species contributing to dissimilarity between communities within locations (inside and outside) each year. Separate SIMPER procedures were also undertaken for species abundance data across years for each location, inside and outside the array, to identify those species contributing to dissimilarity between pre-construction assemblages and each successive year during and post-construction. The resulting top 5 species contributing to the average dissimilarity between each data set were ranked in decreasing order following the method of Gray et al. (1990).

A multivariate comparison of infauna communities at separate distances from inside the array, near the array, mid distance from the array and far from the array across each year was carried out. One – way ANOSIM was used based on Bray-Curtis similarity matrices on square root transformed species abundance data from sample sites. As well as a significance level, the ANOSIM test gives an absolute value on the degree of separation of the assemblage structure characterising locations and years through R values ranging from 0 to 1. This provided a means to examine the significance and degree of separation seen between species assemblages inside the array, and at different distances from the OWF site, over pre and post-construction years, providing a more spatially explicit analysis than the inside and outside comparison.

4.3.2 Fish and epifauna - existing environmental monitoring data

From the historical environmental impact assessment data provided by RWE npower and CMACS Ltd. each individual trawl in each year was treated as an independent sample. To aid comparisons with the results of the BRUV surveys species were only included in the analysis that represented the key species contributing to the *Pleuronectes platessa* - *Limanda limanda* assemblage identified as being characteristic of the sandbank habitats within the study area by Ellis et al. (2000).

Comparisons of abundance of the key fish, shellfish and other invertebrate species were made between samples inside the OWF site (n=4) and samples outside the OWF site (n=8), for the pre-construction year (2001) and the last year of environmental monitoring, three years post-construction (2006) using Mann Whitney *U* tests. Non metric multidimensional scaling (nMDS) was undertaken using the same procedure as for benthic infauna with Bray-Curtis resemblance matrices calculated for each data set. Species abundance data sets were square root transformed data to reduce the influence of the most abundant species. A two-way PERMANOVA design used Bray-Curtis rank similarity matrices, from square root transformed abundance data of key species, to analyse the significance of time (years) and location (inside and outside the OWF site) in influencing dissimilarities between species assemblages. Significance tests of the difference between key species assemblages inside and outside the OWF were performed for each year using one-way ANOSIM. In this instance control sites were separated into two locations, sample sites to the east of the OWF (n=4) and sample sites to the west of the OWF (n=4). The species contributing most to dissimilarities were determined for OWF and control locations in each year by the similarities percentage procedure SIMPER.

4.3.4 Data Analyses – BRUV data (2011)

As with the analyses of fish and epifauna environmental monitoring beam trawl data, comparisons of abundance of key fish, and mobile epifauna were made between samples inside the OWF site (n=36) and outside the OWF site (n=54) using Mann Whitney *U* tests. The two replicate samples from each individual survey site were averaged for multivariate analysis within the PRIMER v 6 statistical analysis package. This provided samples within the OWF array (n=18), referred to as east and west OWF, and samples with the control location to the east of the OWF (n=9), the control location to the west of the OWF (n=9), and the control location to the far west of the OWF (n=9). Data from the three sample points representing the area covered by the environmental monitoring beam trawl tracks were also pooled to create a subsidiary data set. This provided samples within the OWF array of n=6 (referred to as east and west OWF), and n=3 within the eastern control location, western control location and far western control location.

Separate non metric multidimensional scaling (nMDS) was undertaken from Bray-Curtis resemblance matrices calculated from the pooled species abundance data in both data sets. Species abundance data sets had again been square root transformed to reduce the influence of the most abundant species. Significance tests of the difference between key species assemblages inside and at control locations outside the OWF were performed using one-way ANOSIM. The species contributing most to dissimilarities between locations were determined by the similarities percentage procedure SIMPER.

4.3.5 Sediment and Explanatory Environmental variables (2011 BRUV surveys)

Although environmental variables were not collected for 2001-2006 FEPA monitoring epifauna and fish beam trawls, variables were collected for 2011 BRUV data. Water depth, temperature, salinity, estimated sediment type, estimated tidal flow and distance from the western mouth of the Dee Estuary were collected for each replicate sample point in 2011. The BEST test in PRIMER 6 was used to determine which combination of variables had the greatest influence on distribution of fish and mobile epifauna communities identified by the BRUV surveys.

4.4 Results

4.4.1 Benthic infauna – environmental monitoring data 2001-2006.

i) Inside and outside comparisons over time.

A total of 378 species principally across five dominant phyla of Annelida, Bryzoa, Crustacea, Echinodermata and Mollusca were recorded between 2001 and 2006. Mean number of individuals, mean species richness and mean H’ diversity decreased in the construction year and the first year post-construction at sample sites inside and sample sites outside the OWF. Greatest decreases occurred for sample sites within the OWF. Data were collected within the

OWF at 4 sample sites within the array but outside the scour area of monopoles during pre-construction data collection. Data were collected at the same 4 sites and an additional 3 sample sites adjacent to one monopile in the construction year and all post-construction years. A recovery between two and three years post-construction was evident for mean number of individual organisms, mean species number and mean H' (log_e) diversity at both sample locations (Figure 4.2 a, b, c). Mann Whitney *U* tests, comparing samples within the OWF, between baseline data and subsequent construction and post-construction years data, showed a similar pattern to the same comparison for samples collected at sites outside the OWF (Table 4.3). Mann Whitney *U* tests provided a conservative non-parametric test for the non-normal but similar shaped distribution and high variance present in the data. Significant changes in numbers of individuals, numbers of different species and diversity occurred in 2004 across all sites, suggesting regional variation influenced changes and not solely effects of the development (Table 4.3, 4.4, 4.5). Mann Whitney *U* tests were conducted between groups of samples at locations inside and outside the OWF in each year. Significant differences between mean number of individuals, mean number of species and H' (log_e) diversity were present between samples inside and outside the OWF two and three years post-construction (2005 and 2006). Pre-construction samples (2002) and samples one year post-construction (2004) did not display significant difference in diversity (H' (log_e)) or mean number of individuals. A significant difference between locations was seen during construction activity in 2003 with significant differences in H' (log_e) diversity and mean no. of species inside and outside the OWF (Table 4.4). Significant differences in diversity were also seen within sites inside the OWF between 2003 and 2004, and also between 2004 and 2005 (Table 4.5).

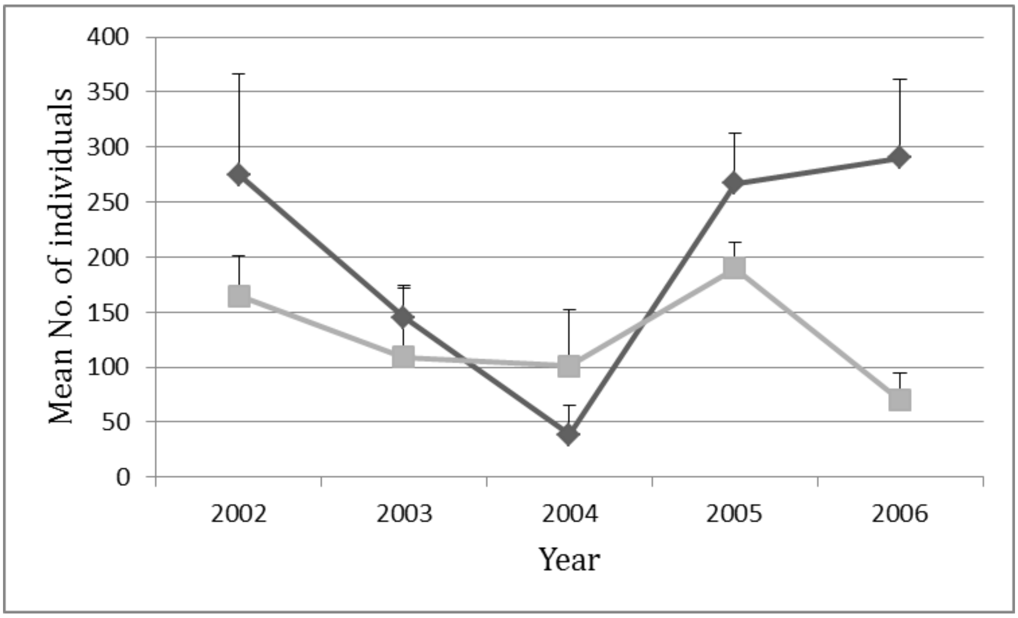


Figure 4.2, a) Mean number of individuals. Comparison of infauna data averaged across sample sites inside (black line) and outside (grey line) North Hoyle offshore OWF from pre-construction (2002) to 3 years post-construction (2006). Vertical lines represent standard error.

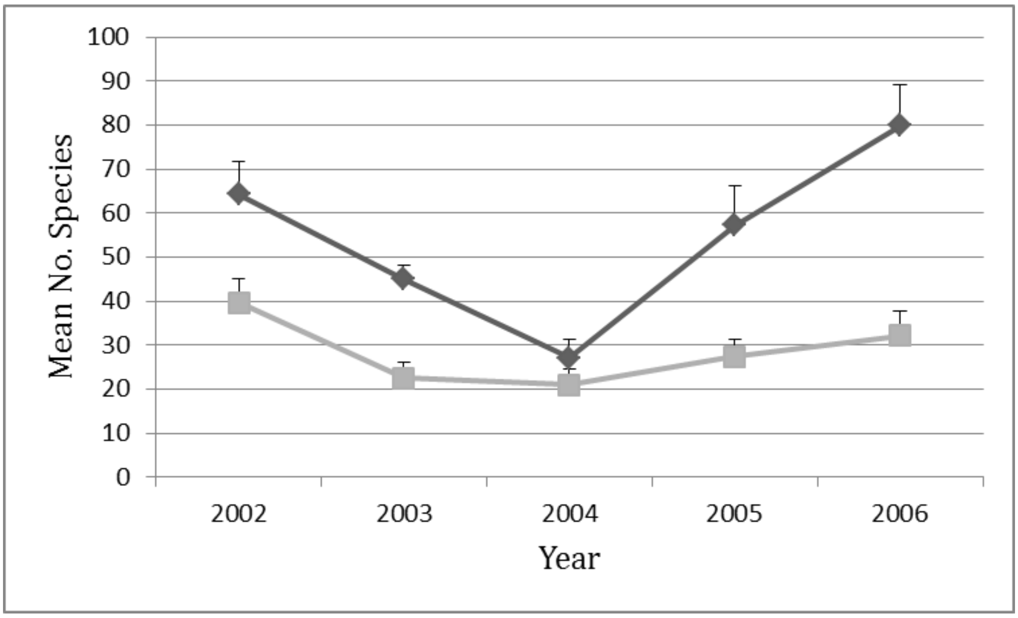


Figure 4.2, b. Mean numbers of species. Comparison of infauna data averaged across sample sites inside (black line) and outside (grey line) North Hoyle offshore OWF from pre-construction (2002) to 3 years post-construction (2006). Vertical lines represent standard error.

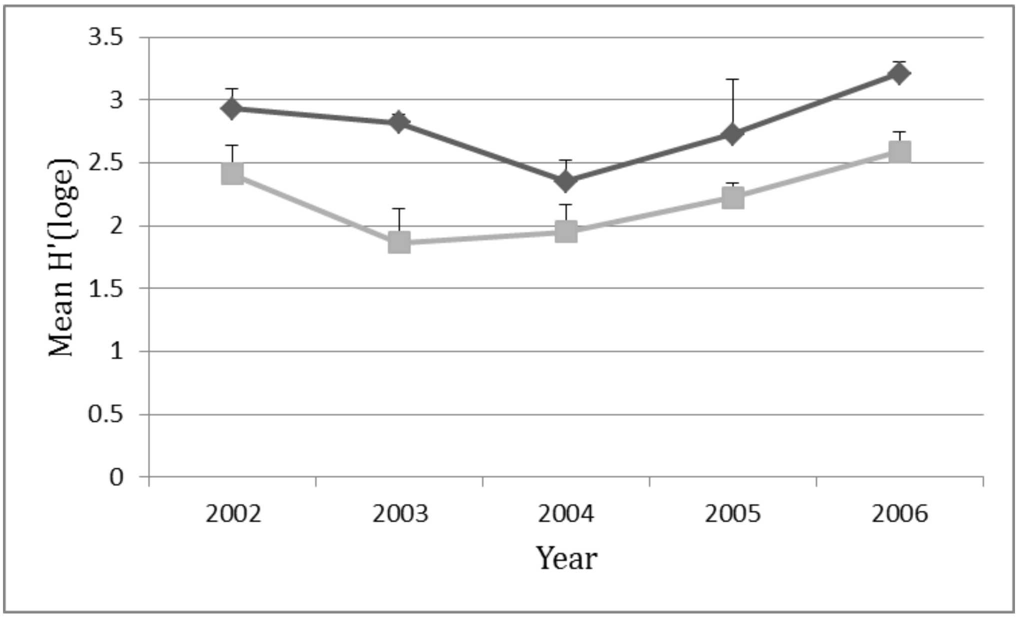


Figure 4.2, c. Mean Shannon diversity H' (log_e). Comparison of infauna data averaged across sample sites inside (black line) and outside (grey line) North Hoyle offshore OWF from pre-construction (2002) to 3 years post-construction (2006). Vertical lines represent standard error.

Table 4.3 Mann Whitney U test significance (*p*) values of tests between baseline infauna data and subsequent years data. Values to the left of each column are samples compared from within the OWF array; values to the right are comparisons within samples from outside the array.

Comparisons between baseline and post construction years, inside / outside Mann Whitney U test *p* values (*significant values = < .05)			
	Mean no. individuals	Mean no. species	H' (loge) diversity inside/outside
2002, 2003	0.39 / 0.02*	0.05*/ 0.04*	0.78 / 0.1
2002, 2004	0.03* / 0.03*	0.01* / 0.01*	0.05* / 0.15
2002, 2005	0.83 / 0.15	0.98* / 0.16	0.59 / 0.24
2002, 2006	0.96 / 0.02*	0.45 / 0.35	0.16 / 0.84

Table 4.4 Mann Whitney *U* test statistic and *p* values (in brackets) from tests of mean number of individuals, mean number of species and H' (log_e) diversity between sample sites in each location inside and outside for each survey year for infauna community data, * values are significant at 5%, p=0.05.

	Mean no. individuals	Mean no. species	H' (loge) diversity
2002	10 (0.157)	5.5 (0.048*)	11 (0.203)
2003	19 (0.118)	4 (0.02*)	6 (0.05*)
2004	30 (0.874)	20.5 (0.24)	18 (0.153)
2005	4 (0.005*)	2 (0.002*)	2 (0.002*)
2006	3 (0.002*)	2 (0.002*)	8 (0.013*)

Table 4.5 Mann Whitney *U* test *p* values from tests of mean number of individuals, mean number of species and H' (log_e) diversity between each survey year for sample sites in each location (inside and outside), * values are significant at 5%, p= < 0.05.

	Mean no. individuals inside/outside	Mean no. species inside/outside	H' (loge) diversity inside/outside
2002, 2003	0.41 / 0.1	0.083*/ 0.035*	0.570 / 0.105
2003, 2004	0.053 / 0.77	0.013* / 0.72	0.026* / 0.968
2004, 2005	0.005* / 0.9	0.002* / 0.18	0.008* / 0.161
2005, 2006	0.1 / 0.97	0.165 / 0.6	0.837 / 0.222

Species communities at sample sites altered in subsequent years both during and post-construction from the baseline conditions recorded in 2002. The non-metric multidimensional scaling (nMDS) plot of species abundance data at each sample site across all years shows observable difference between years in communities at individual sample sites (Fig 4.3a). The most distinct difference appears for sample sites within the OWF array and the separation of inside and outside locations during construction and OWF operation years. In 2004 (one year post-construction), all sample sites inside the OWF appear at greater distances from positions in all other years. By 2005 and 2006 samples from within the OWF are separated from samples within the OWF in previous years, (sample sites adjacent to a single monopile (18, 19, 20) show the greatest separation from other samples) (Fig 4.3 b). These inter-annual differences are less clear in samples from control locations, although sample sites outside the array displayed greater variability within years than sample sites within the OWF array (Fig 4.3 c). It is unclear from the nMDS plots alone whether fluctuating species communities are due to construction and presence of the OWF or natural variation. To examine the extent separation in the before, after, control, impact (BACI) species community data PERMANOVA and ANOSIM tests were conducted.

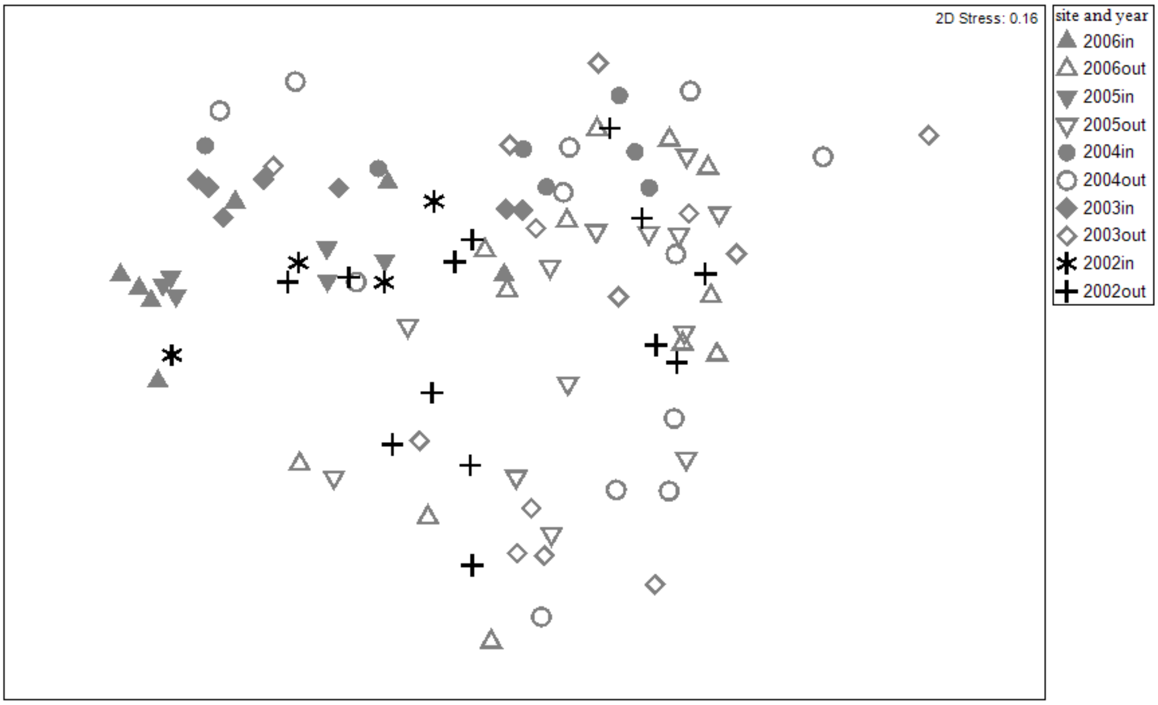


Figure 4.3a) All sample sites inside the OWF and all control sites outside the OWF 2002-2006.

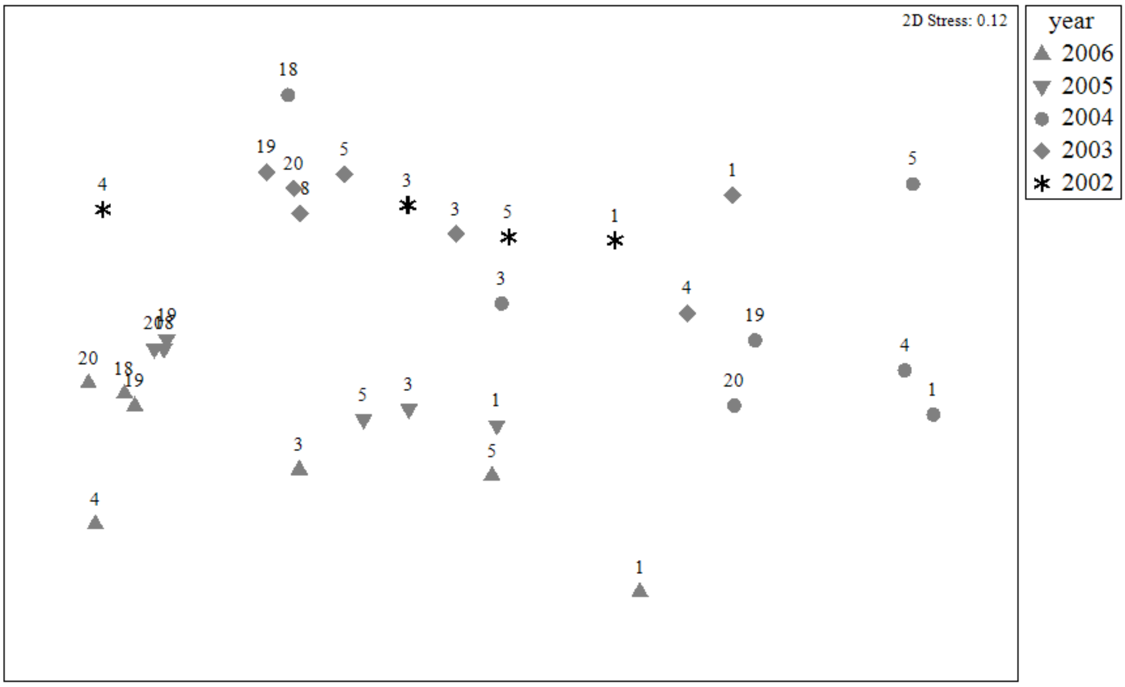


Figure 4.3 b) Sample sites inside North Hoyle OWF only: 2002-2006. Numbers refer to the sample site.

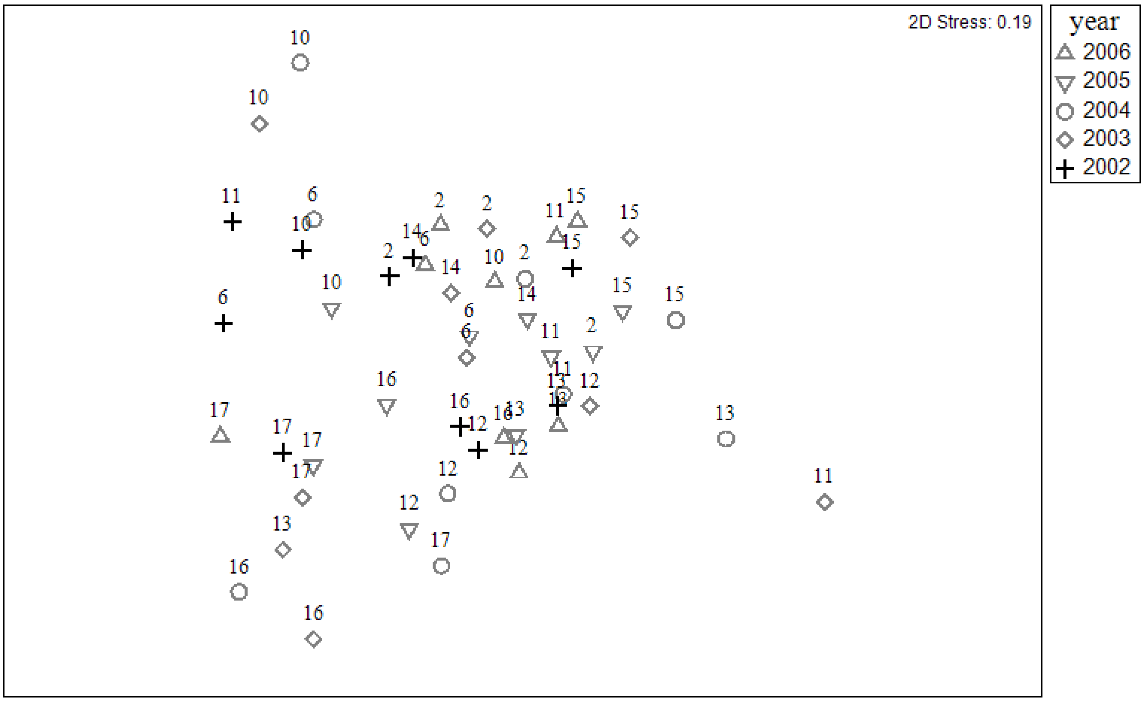


Figure 4.3 c), Sample sites in control locations outside the North Hoyle OWF only: 2002-2006. Numbers refer to the sample site

Figure 4.3 Non metric multidimensional scaling plots of the Bray-Curtis similarity matrix calculated from square root transformed benthic community data for all sample sites inside (solid shapes and black stars) and outside (hollow shapes and crosses) the North Hoyle offshore OWF across pre-construction (2002) and post-construction (2003-2006) years for (a) all sample sites, b) samples from sites within the OWF only and c) samples from outside the OWF only.

The two way PERMANOVA test revealed significant effects for both location (pseudo F = 10.78, significance = 0.001%) and time (pseudo F = 3.25, significance = 0.001%) with a significant interaction effect (pseudo F = 1.73, significance = 0.002%). One way ANOSIM tests displayed high R values and identified significant differences between locations (inside and outside) for each year apart from the baseline communities (2002) and communities one year post-construction (2004) (Table 4.6).

Table 4.6. ANOSIM test R statistic and significance level % of benthic infauna communities inside and outside North Hoyle offshore OWF for each year, 2002 (pre-construction) to three years post-construction (2006). Tests were carried out on square root transformed mean abundance data from sample sites. * indicates significant result at p= < 0.05 (5%).

Year comparison	R Statistic	Significance %
2002in, 2002out	0.035	36
2003in, 2003out	0.249	1.3*
2004in, 2004out	-0.06	70.2
2005in, 2005out	0.593	0.2*
2006in, 2006out	0.582	0.1*

ii) Effect of distance from the wind farm site.

Post-construction a significant difference developed between species communities within the OWF site and reference sites situated at greater distances from the OWF. Pre-construction (2002) communities from sites within the OWF site and communities from sites up to 4 miles outside the array showed no significant difference in an ANOSIM test (Table 4.7). Although communities inside the OWF and reference sites beyond 4 miles from the OWF site were significantly different (Table 4.7). During construction all communities at reference sites at each distance were significantly different to those in the OWF site. OWF communities and near and middle distance reference sites returned to being similar in 2004 but significant differences re-appeared in 2005 and 2006 comparisons (Table 4.7).

Table 4.7. ANOSIM test *R* statistic and significance level % of benthic infauna community comparisons between samples within the OWF site and samples from sites at increasing distance from the OWF for each survey year. 1=inside, 2=samples within 2 miles, 3=samples within 2-4miles, 4=samples from greater than 4 miles from the OWF. Values where p < 5% are indicated *.

	Distance comparisons 1 = inside, 2 = near, 3 = mid and 4 = far		
	1,2	1,3	1,4
2002	0.083 (71.6)	0.219 (8.6)	0.438* (3.2)
2003	0.675* (0.3)	0.505* (1.2)	0.639* (0.1)
2004	0.04 (26.4)	0.216 (9.4)	0.415* (1.5)
2005	0.98* (0.5)	0.635* (0.5)	0.875* (0.2)
2006	0.63* (0.9)	0.616* (0.6)	0.817* (0.3)

iii) Effect of change of sediment (mean grain size)

A significant increased mean sediment size is evident within the OWF in the construction year (2003) in comparison with sediment samples from control sites (Mann Whitney *U* test p=0.013). One year post-construction (2004) a large decrease in mean grain size was seen for sample sites within North Hoyle OWF, however this decrease was not statistically significant (Fig 4.4) (Mann Whitney *U* test p = 0.128). The non-metric multidimensional scaling plot of Bray Curtis similarity measures and ANOSIM results show species communities in the OWF were dissimilar to reference communities outside in all years except 2002 and 2004 (Fig 4.3 a, b, c, Table 4.4). Overlaying mean grain size of sediments on sample points in the nMDS indicated grain size suggested an explanation for some of the distribution. Larger grain sizes occurred post-construction in samples in immediate proximity to a single monopile (sites 18, 19, 20), and at other sample sites inside the OWF (but outside the immediate monopile footprint) (Fig 4.5). The RELATE test indicated a significant small positive correlation (Spearman correlation = 0.226, significance level 0.1%) indicating patterns in the biological Bray-Curtis resemblance matrix of species assemblages at sample sites are quite similar to patterns in the environmental resemblance matrix of sediment mean grain size (mm).

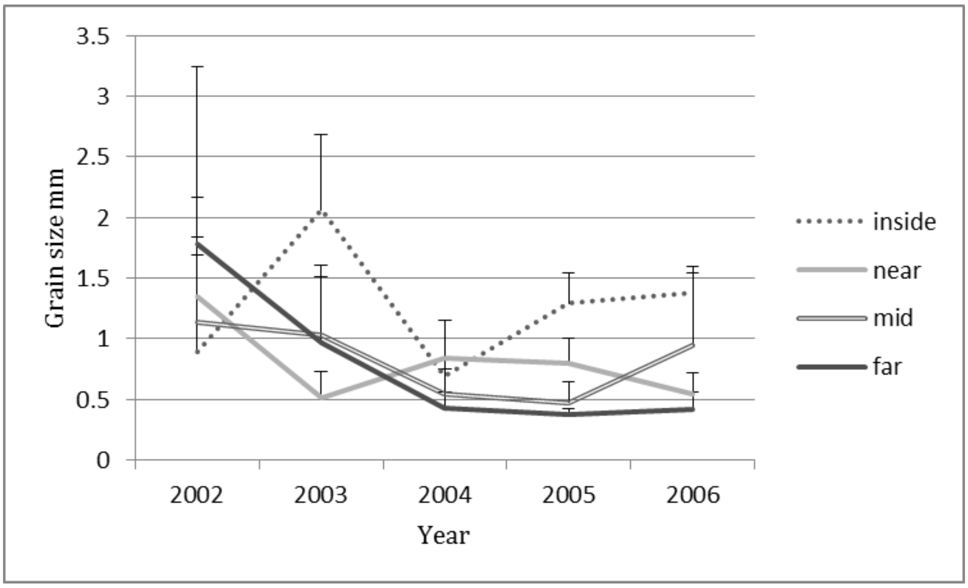


Figure 4.4. Mean grain size averaged between sample sites inside the OWF array (dotted line) at control sites near (under 2 miles) from the OWF (light grey line), middle distance (2-4 miles) from the OWF (hollow grey line) and at far distances (> 4 miles) (dark grey line) across survey years (2002-2006).Vertical lines represent standard error.

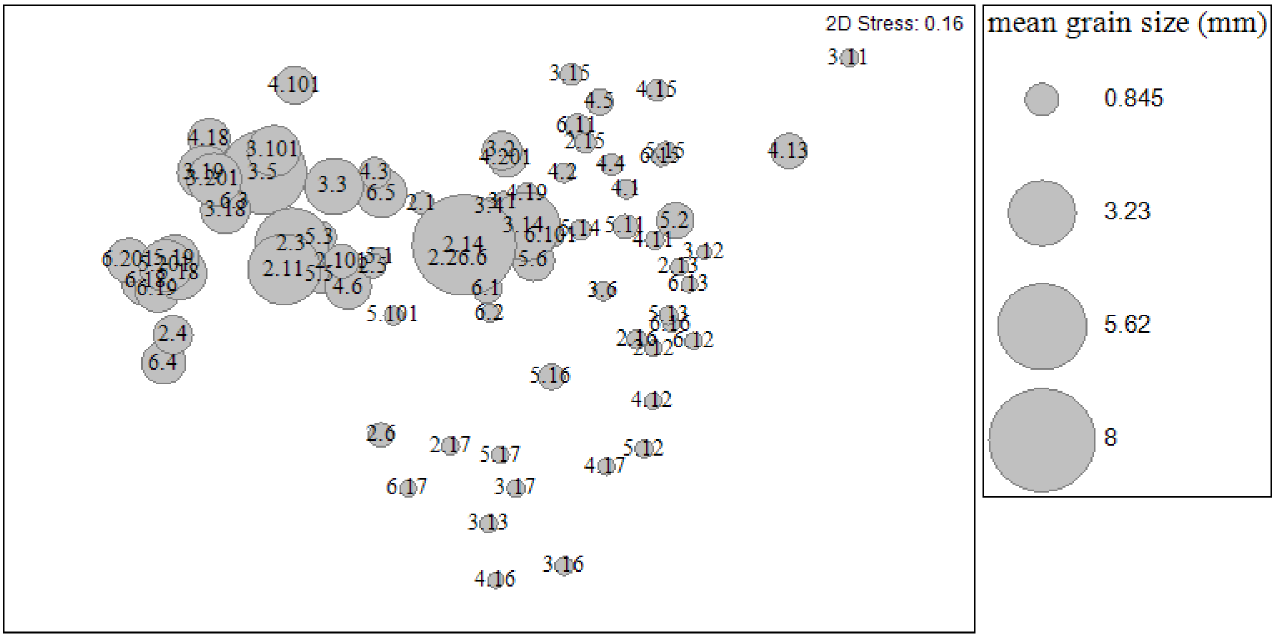
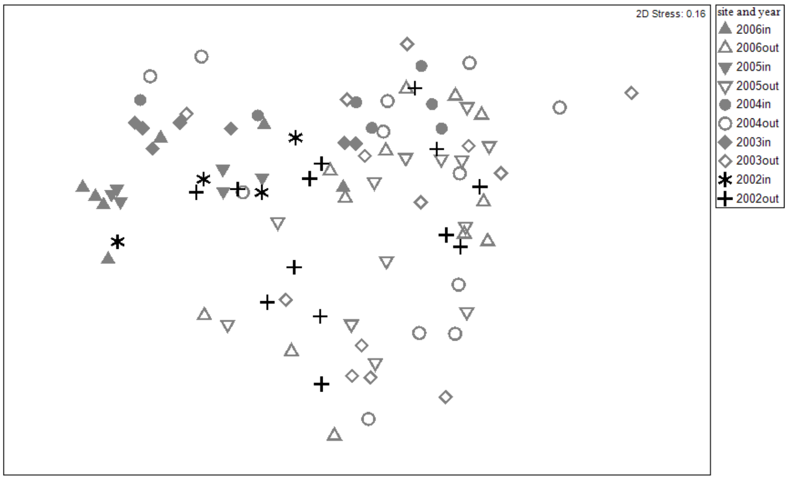


Figure 4.5. Mean grain size expressed as increasing sized grey circles at each of the infauna sample points from inside and outside the OWF and each year 2002-2006.The first number of each label refers to year; 2, 2002; 3, 2003; 4, 2004; 5, 2005; 6, 2006. The second number of the label refers to the sample site (101 refers to sample site number 10). Fig 4.3a (below) is reproduced for reference purposes.



iv) Species contributing to dissimilarity between communities at locations (SIMPER)

The species contributing most to dissimilarities identified by ANOSIM tests between communities at sample locations inside and outside the OWF in 2003, 2005 and 2006 were investigated using SIMPER. Post-construction greater average abundance of *Aonides paucibranchata* and lower abundance of *Donax vittatus* within the OWF in comparison with samples outside the OWF dominated the high average dissimilarity in communities between locations (Table 4.8). Only two species (on single occasions), which were present as important contributors to dissimilarity between locations in baseline (2002) samples, were important in further comparisons of locations within years (increased abundance of *Sagartidae sp.* in 2005 and increased abundance of *Ophelia borealis* in 2004 within the OWF) (Table 4.8).

SIMPER results investigating the species contributing highest to changes over time, inside OWF sample sites and separately for sample sites outside the OWF, show greater fluctuations occurred in communities inside the OWF. Species contributing to dissimilarity over time outside the OWF remained consistent. However, within the OWF abundance of highest contributing species between pre-construction and construction conditions decreased over time. Previously rare species increased in abundance in samples from within the OWF, and so contributed to dissimilarity in post-construction years (Table 4.9). Over post-construction years at sample sites outside North Hoyle OWF, only two species added to the original top 5 species contributing to dissimilarity between 2002 (pre-construction) and 2003 (post-construction) suggesting similar communities persisted over time (Table 4.10). The same SIMPER analysis for sites inside the array displays a total of 8 new species appearing across the top 5 contributing species for 2002, 2004; 2002, 2005 and 2002; 2006 comparisons suggesting greater variability in communities between years (Table 4.9).

Table 4.8. SIMPER comparison of the % contributions of the 5 most important species contributing to Bray Curtis dissimilarity between square root transformed mean abundance infauna data from inside the OWF and outside the OWF within each survey year. 'I' indicates abundance greater for that species inside the OWF, 'O' indicates abundance greater outside for each comparison.

Species	2002 % contribution	abundance greatest inside (I) or outside (O)	2003%		2004%		2005%		2006%	
Sagartiidae sp.	3.89	I					3.71	I		
Cirratulidae sp. (Juv.)	3.68	I								
Polycirrus medusa	3.39	I								
Ophelia borealis	3.29	I			4.36	I				
Mediomastus fragilis	2.65	I								
Aonides paucibranchiata			5.78	I			3.6	I	2.63	I
Donax vittatus			4.2	O	4.59	O	3.11	O		
Protodorvillea kefersteini			3.66	I					2.66	I
Nematoda spp.			3.59	I						
Pisione remota			3.44	I	4.22	I				
Spisula elliptica					3.84	O				
Nephtys cirrosa					3.53	I				
Mysella bidentata							4.02	I		
Lagis koreni							3.1	I		
Pista cristata									2.89	I
Nemertea spp.									2.87	I
Ampharete lindstroemi									2.23	I
Average dissimilarity (Bray-Curtis)	72.18		81.11		75.88		82.51		83.64	

Table 4.9. Comparison of the 5 most important species % contributions to dissimilarity between pre-construction species communities (2002) and species communities from samples in construction (2003) and post-construction years (2004-2006) at sites inside North Hoyle offshore wind farm. ↑ and ↓ indicates mean √ transformed abundance increases or decreases respectively in reference to the baseline data.

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Species	Contribution to dissimilarity (%) 2002, 2003	Contribution to dissimilarity (%) 2002, 2004	Contribution to dissimilarity (%) 2002, 2005	Contribution to dissimilarity (%) 2002, 2006
Sagartiidae sp.	3.7 ↓		4.25 ↓	3.4 ↓
Aonides paucibranchiata	3.51 ↑			
Cirratulidae sp. (Juv.)	3.12 ↓	3.34 ↓	2.37 ↓	
Ophelia borealis	2.91 ↓		2.28 ↓	2.24 ↓
Protodorvillea kefersteini	2.55 ↑			
Polycirrus medusa		4.12 ↓		
Sagartiidae sp.		3.63 ↓		
Mediomastus fragilis		3.19 ↓		
Nematoda spp.		2.9 ↓		
Mysella bidentata			2.92 ↑	
Pista cristata			2.2 ↑	2.41 ↑
Nemertea spp.				2.81 ↑
Nematoda spp.				2.36 ↓
Average dissimilarity	63.52	75.02	65.85	72.75

Table 4.10. Comparison of the 5 most important species % contributions to dissimilarity between pre-construction species communities (2002) and species communities from samples in construction (2003) and post-construction years (2004-2006) at sites outside North Hoyle offshore wind farm. ↑ and ↓ indicates mean √ transformed abundance increases or decreases respectively in reference to the baseline data.

Species	Contribution to dissimilarity (%) 2002, 2003	Contribution to dissimilarity (%) 2002, 2004	Contribution to dissimilarity (%) 2002, 2005	Contribution to dissimilarity (%) 2002, 2006
Donax vittatus	6.62 ↑	4.79 ↑	6.42 ↑	2.93 ↓
Cirratulidae sp. (Juv.)	4.4 ↓	3.31 ↓	3.33 ↓	3.14 ↓
Bathyporeia guilliamsoniana	4.08 ↓	3.79 ↓	3.38 ↓	
Nephtys cirrosa	3.07 ↓	3.03 ↓		
Magelona johnstoni	2.48 ↓	3.12 ↓	4.51 ↑	4.14 ↑
Sagartiidae sp.			3.79 ↑	
Bathyporeia elegans				3.51 ↓
Owenia fusiformis				2.33 ↑
Average dissimilarity	78.18	80.24	74.39	77.28

4.4.2 Fish and Epifauna – environmental monitoring data 2001-2006

i) *Inside and outside comparisons over time.*

During 5 years of monitoring, beam trawls collected 30 fish species, 23 Crustacean species, 21 Mollusc species, 7 echinoderm species, 5 Annelida species and 10 species of Bryozoans and Cnidarians across the survey site. These included all the key species identified as representative of sandbank habitats in the Eastern Irish Sea (Ellis et al. 2000). Abundance of the flatfish species *Solea solea* decreased significantly within the OWF between pre-construction samples (2001) and samples from 3 years post-construction (2006) (Mann Whitney U $p = 0.03$). Abundance of brittle star species (Ophiuroidea) and goby species (Pomatoschitus) increased significantly within the OWF in the same comparison (Mann Whitney U $p = 0.03$ and $p = 0.03$). At sample locations outside the OWF abundance of flatfish species, dab (*Limanda limanda*), brittle starfish species (Ophiuroidea) and goby species (Pomatoschitus sp.) increased significantly between pre-construction and 3 years post-construction data (Mann Whitney U $p = 0.01$, $p = 0.001$, $p = 0.03$ respectively). Only hermit crab (*Pagarus pagarus*) abundance decreased significantly three years post-construction in comparison to pre-construction abundance for reference sites outside the OWF (Mann Whitney U, $p = 0.03$).

As with benthic infauna community samples fish and epifauna communities changed both during and post-construction from the baseline conditions. The non-metric multidimensional scaling (nMDS) plot of species abundance data at each sample site across all years showed observable difference between years in communities at individual sample sites in 2001 (pre-construction) to other years (Fig 4.6 a). Separate nMDS plots for communities at sample sites inside the OWF and sample sites outside indicated a more distinct difference between communities at sample sites within the OWF (Fig 4.6 b, c). The greatest difference occurred between communities within pre-construction samples (2001) and construction samples

(2003) within the OWF (Fig 4.6 b). Post-construction samples (2004-2006) appeared more uniform but separate from both pre-construction and during construction communities (Fig 4.6 b).

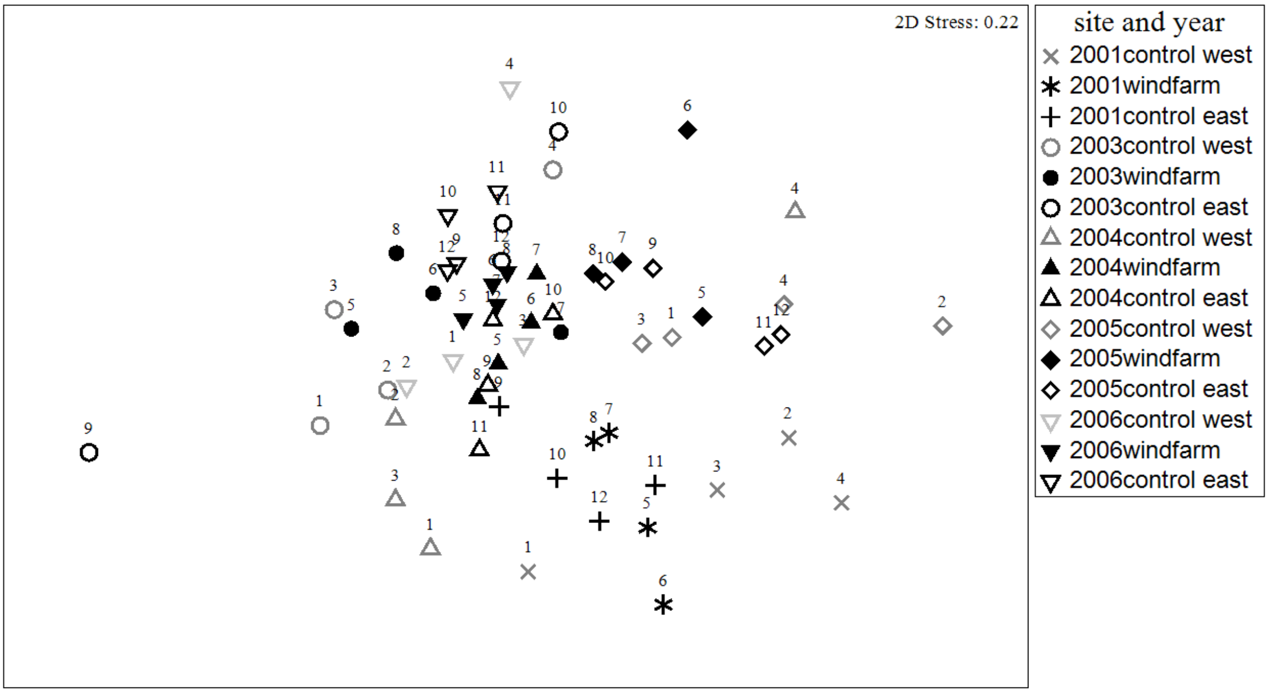


Fig 4.6 a. All sample sites inside and outside North Hoyle OWF

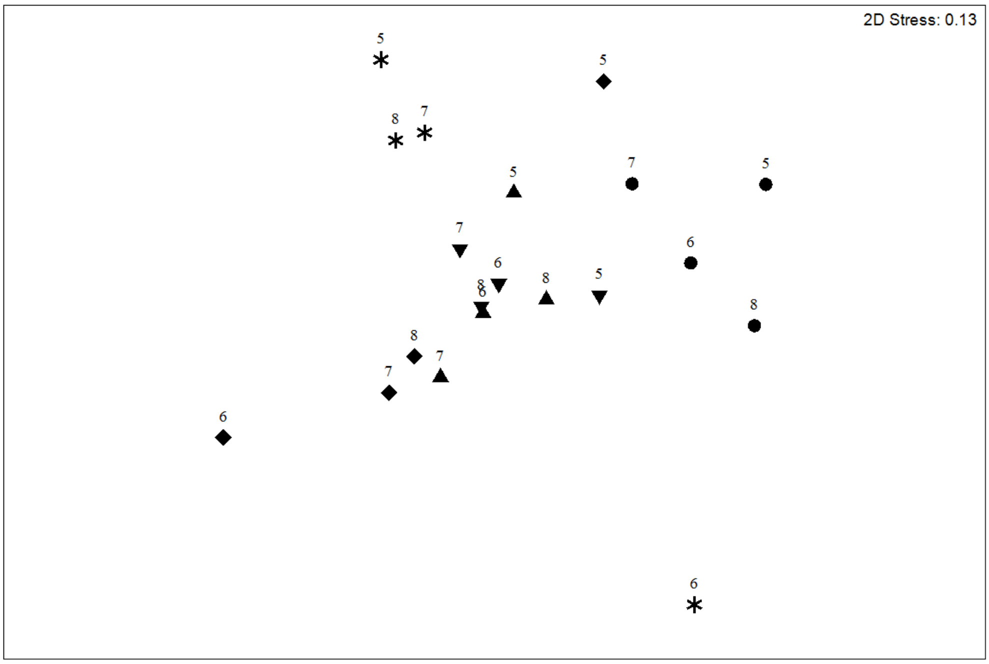


Fig 4.6 b. sample sites inside North Hoyle OWF only

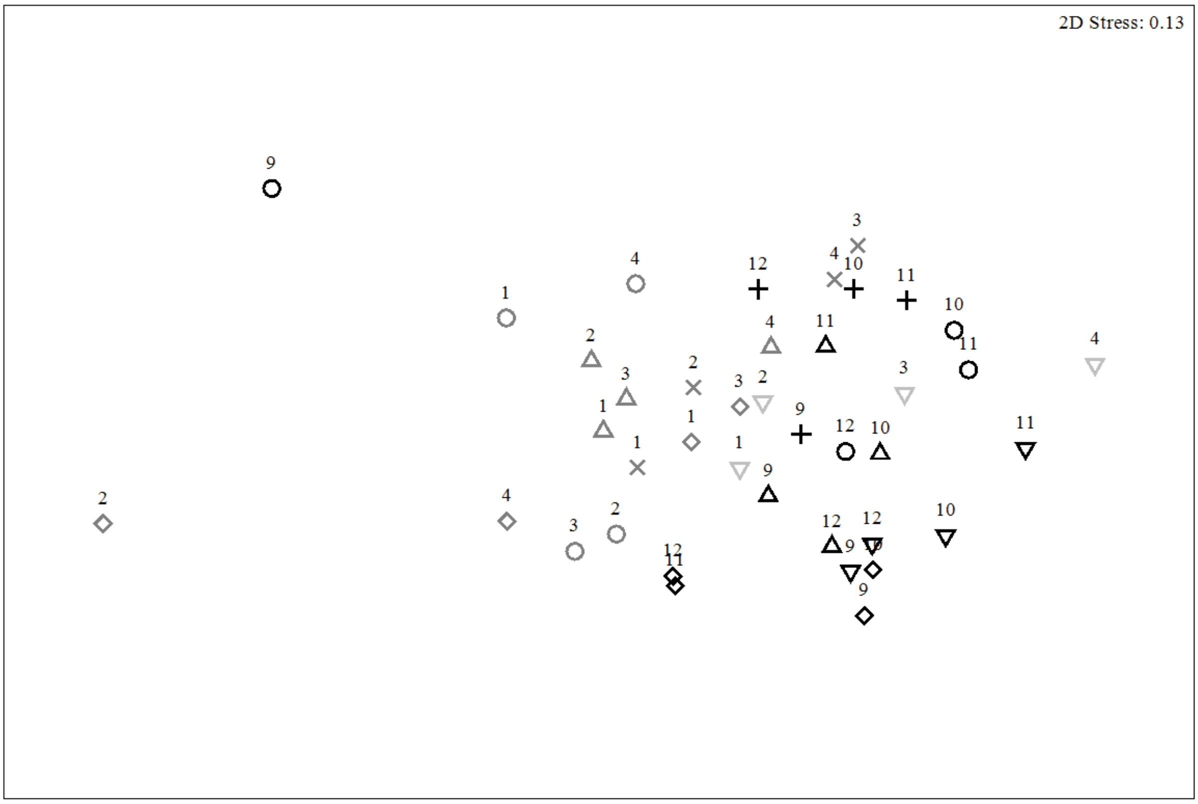


Fig 4.6 c Samples sites outside North Hoyle OWF only

Figure 4.6. a) Non metric multidimensional scaling plot of Bray Curtis similarity matrix calculated from square root transformed epifauna and fish beam trawl data, a) from all sample sites inside North Hoyle OWF (solid shapes) and control sites outside the OWF site (hollow shapes) labels refer to sample site. b) Sample sites inside North Hoyle OWF only, c) sample sites outside the OWF only. Labels refer to sample site in all plots.

The two way PERMANOVA test revealed significant effects for both location and time with a significant interaction effect (Table 4.11). One way ANOSIM tests for difference between location (OWF and control locations to the east and west of the OWF) displayed high *R* values indicating differences between the OWF and each control location during construction (2003) and one year post-construction (2004). *R* values suggested communities within OWF samples continued to be dissimilar to samples to the west of the OWF, two and three years post-construction (2005, 2006) but with a significant difference only present in 2006 (R = 0.396, significance 2.9%). Communities within OWF and control samples to the east of the

OWF, however, show some overlapping in species composition and abundance emerging in these years (Table 4.12).

Table 4.11. Results of two-way PERMANOVA test between time (year) and location (inside and outside the offshore wind farm) for benthic trawl surveys of fish and epifauna.

Source	df	SS	MS	Pseudo-*F*	*P* (perm)	Unique perms
Time (year)	4	42301	10575	7.4674	0.001	998
Location (inside or outside)	1	3653.3	3653.3	2.5797	0.01	998
Time x Location	4	7830.2	1957.6	1.3823	0.051	997

Table 4.12. Results of ANOSIM tests between species communities occurring within the OWF array and control sites to the east of North Hoyle OWF and control sites to the west of North Hoyle OWF within each year 2001 (pre-construction), 2003 (during construction) and 2004-2006 (post-construction years). * indicates significant differences. (R values ranging from 0 to 1 (R > 0.75, well separated species communities; R > 0.50, overlapping but clearly different; R < 0.25, barely separable at all (Clarke and Gorley 2001, 2006).

	windfarm, control east		windfarm, control west	
	R=	(Sig.%)	*R*=	(Sig.%)
2001	0.1	(94.3)	0.01	(37.1)
2003	0.417	(5.7)	0.25	(5.7)
2004	0.865	(2.9*)	0.469	(5.7)
2005	0.302	(14.3)	0.354	(8.6)
2006	0.323	(11.4)	0.396	(2.9*)

Before construction greater abundance within the OWF site of the fish species, *S. Solea* and *E. vipera*, the Echinoderm species, Ophiuroidea, and *A.rubens* and one crustacean species, *P.bernhardus* characterised a very small and variable average dissimilarity (43%), between samples inside and outside the OWF site (Table 4.11 a). Increased abundance of Ophiuroidea and large fluctuations in abundance of *A.rubens* within OWF samples, dominated higher dissimilarity between locations in construction and post-construction years. Average dissimilarity between pre-construction and post-construction community samples was greatest for samples within the OWF. Dissimilarity within OWF samples ranged from 52.81% to 67.14% as opposed to a range between 44.58% and 57.68% for communities at control locations (Table 4.11 b, c). Dissimilarity between pre and subsequent post-construction communities within the OWF samples was dominated by very large increases in abundance of brittle stars (Ophiuroidea). Decreased abundance of flatfish species (*S.solea and P.platessa*) and the crustacean *P.bernhadus* also consistently characterised dissimilarity between years within OWF samples post-construction (Table 4.11 b).

ii) Species contributing to dissimilarity between communities at locations (SIMPER)

Table 4.13. Comparison of the % contribution to dissimilarity of the 5 most important species based on square root transformed mean abundance data from a) samples of fish and epifauna from inside the OWF to those outside the OWF within each survey year. 10 b) fish and epifauna data from samples between baseline, pre-construction data post-construction and post-construction samples inside North Hoyle OWF. 10 c) fish and epifauna data from samples between baseline, pre-construction data post-construction and post-construction samples within control locations outside North Hoyle OWF.

a) Inside and outside North Hoyle OWF comparison 'I' indicates abundance greater for that species inside the OWF, 'O' indicates abundance greater outside for each comparison.

Species	2001 % contribution	abundance greatest inside (I) or outside (O)	2003%		2004%		2005%		2006%	
Asterias rubens	36.62	I	22.19	O	16.47	I	29.39	I	25.59	O
Pagurus bernhardus	15.34	I	16.87	I	6.24	I	5.28	I	5.32	O
Solea solea	9.04	I								
Echiichthys vipera	7.01	I	9.69	I					12.51	O
Ophiura spp	6.64	I			53.42	I	48.15	I	23.37	I
Liocarcinus holsatus	5.85	O	11.97	O					9.81	O
Liocarcinus depurator			11.82	I						
Limanda limanda			7.65	O					6.55	O
Pleuronectes platessa					6.06	O				
Average dissimilarity (Bray-Curtis)	43.43		52.66		42.84		62.38		36.75	

Table 4.13 b. Comparison of construction and post-construction samples with baseline pre-construction communities inside North Hoyle OWF. ↑ indicates mean √ transformed abundance increases in reference to the baseline data. ↓ indicates mean √ transformed abundance decreases in reference to the baseline data.

Species	Contribution to dissimilarity % 2001,2003	Contribution to dissimilarity % 2001,2004	Contribution to dissimilarity % 2001,2005	Contribution to dissimilarity % 2001,2006
Asterias rubens	28.4 ↓	23.54 ↓	28.87 ↑	22.43 ↓
Ophiura spp	10.36 ↑	41.49 ↑	43.51 ↑	37.14 ↑
Pagurus bernhardus	10.28 ↓	9.71 ↓	6.07 ↓	10.14 ↓
Liocarcinus depurator	9.03 ↑		3.92 ↑	
Pleuronectes platessa	8.54 ↓	4.85 ↓	3.97 ↓	4.17 ↓
Solea solea	7.85 ↓	6.45 ↓	4.59 ↓	7.76 ↓
Echiichthys vipera	7.13 ↑	4.65 ↓		4.52 ↑
Liocarcinus holsatus	6.07 ↑		3.92 ↑	
Limanda limanda	4.4 ↓			4.9 ↑
Average dissimilarity	67.14%	57.54%	65.91%	52.81%

Table 4.13 c. Comparison of construction and post-construction samples with baseline pre-construction communities outside North Hoyle OWF. ↑ indicates mean √ transformed abundance increases in reference to the baseline data. ↓ indicates mean √ transformed abundance decreases in reference to the baseline data.

Species	Contribution to dissimilarity % 2001,2003	Contribution to dissimilarity % 2001,2004	Contribution to dissimilarity % 2001,2005	Contribution to dissimilarity % 2001,2006
Asterias rubens	30.44 ↓	25.15 ↓	31.07 ↓	21.32 ↑
Pagurus bernhardus	12.63 ↓	16.96 ↓	14.11 ↓	9.95 ↓
Liocarcinus holsatus	9.72 ↑	6.47 ↓	6.39 ↓	8.25 ↑
Liocarcinus depurator	7.71 ↑			
Echiichthys vipera	6.77 ↑	8.53 ↓	7.96 ↓	11.11 ↑
Pleuronectes platessa	6.37 ↓		7.34 ↓	
Limanda limanda	5.38 ↑	7.74 ↑		7.92 ↑
Ophiura spp	5.09 ↓	15.97 ↑	18.83 ↑	22.28 ↑
Average dissimilarity	57.68%	44.58%	55.84%	51.20%

4.4.3 Mobile fish and epifauna - BRUV data (2011)

i) Inside and outside comparisons

In 90 BRUV samples from within the OWF (n=36), and at near and far reference locations (n=54) a total of 1015 fish and mobile epifauna organisms were recorded per minute of video in 2011, collected 8 years post-construction of North Hoyle OWF. Abundance of flatfish species (Pomatoschitus), brittle star species (Ophiuroidea), and the elasmobranch, *(Scyliorhinus stellaris)* were significantly greater at sample sites within reference locations compared with sample sites within the OWF (Mann Whitney U tests p = 0.001, 0.05, 0.001, 0.01 respectively). Abundance of the hermit crab, *Pagarus bernhardus* was significantly greater within the OWF (Mann Whitney U test p=0.001) (Fig 4.7).

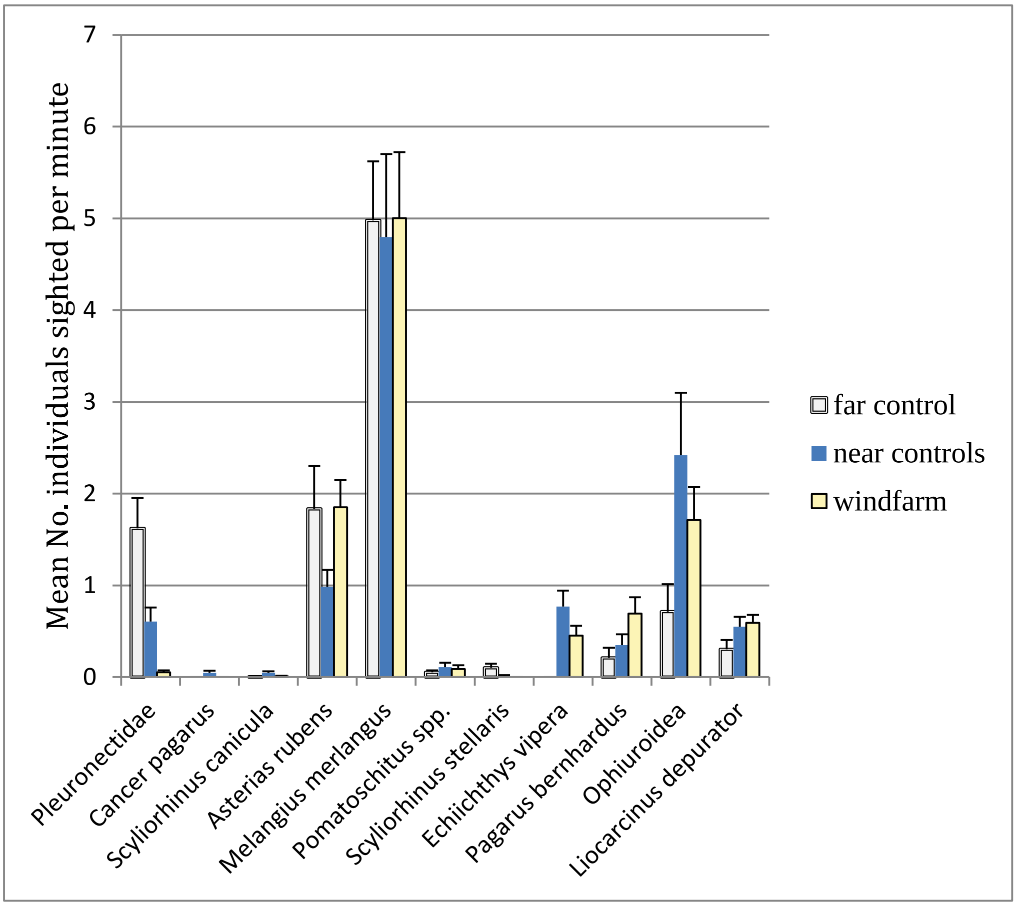
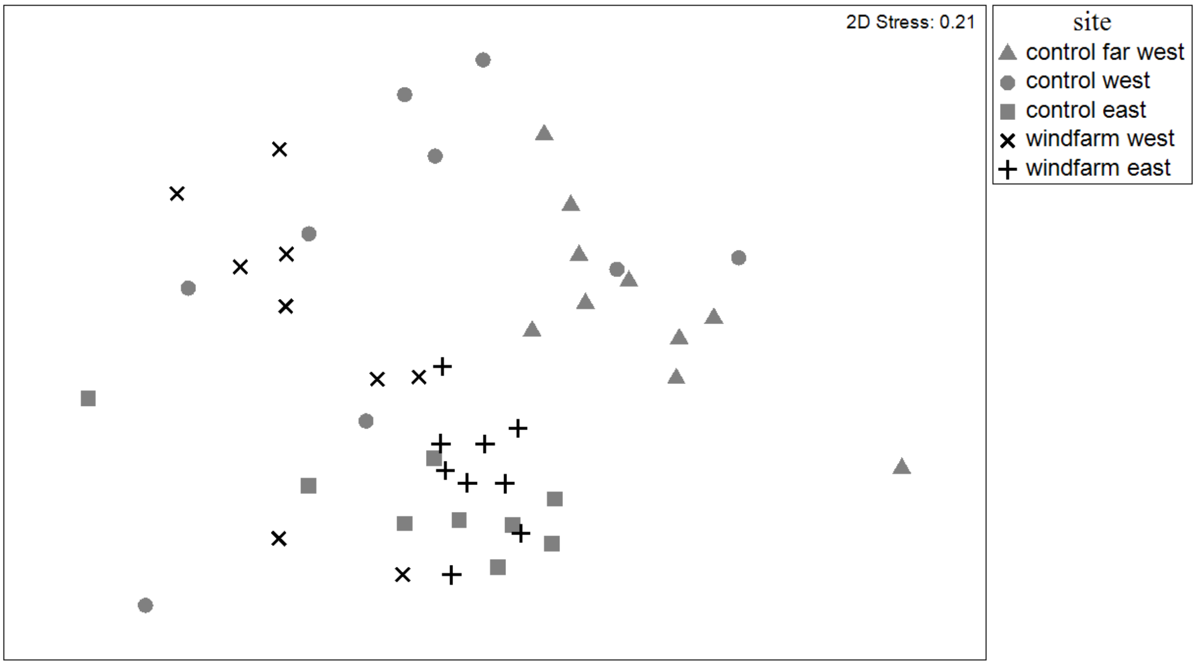
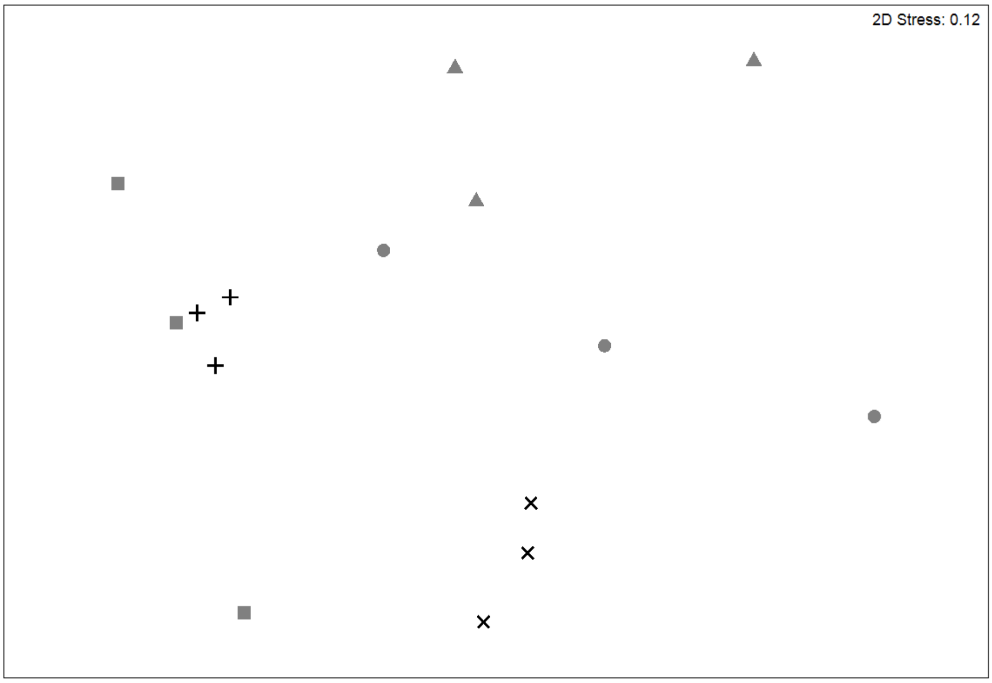


Figure 4.7. Mean species abundance (sightings per minute within BRUV samples) for each key species within the three survey locations, the OWF site, near controls (east and west) and far west control (Error bars represent S.E.).

Non-metric multidimensional scaling (nMDS) plots of Bray Curtis dissimilarity calculated from square root transformed species abundance data at each sample sites show a separation between western control locations and the OWF and eastern control locations (Fig 4.8 a, b). Both the nMDS plots and ANOSIM tests showed a continuation of the trend seen in the last two years of post-construction environmental monitoring beam trawls in 2005 and 2006. Samples from reference locations to the west of the OWF have dissimilar community structures to those within the OWF and to samples in the eastern control site (Figure 4.8 a, b, Table 4.14). Within the OWF site and in samples from reference sites to the east species presence and abundance have greater similarity. The greatest distinction is between communities from samples at the far western control location and those within the OWF and to the east of the OWF (Figure 4.8 a, b, Table 4.14). This is clearly displayed in the resulting nMDS of the Bray Curtis similarity matrix when square root transformed species abundance data is averaged (pooled) from all BRUV samples at each FEPA license related environmental monitoring trawl location (Fig 4.8 b).



a) square root transformed data that has been averaged from the two replicate BRUV samples at each survey point within each location (n=9 within each location).



b) square root transformed data averaged from six replicate BRUV samples taken from survey sites grouped around 2001-2006 environmental monitoring beam trawl tracks within each location (n=3 in each location with OWF locations labelled as east and west OWF).

Figure 4.8. Non metric multidimensional scaling plots of Bray Curtis similarity matrices calculated from square root transformed fish and mobile epifauna BRUV sample data inside North Hoyle OWF (crosses) and control sites outside the OWF site (solid shapes).

Table 4.14. ANOSIM test *R* statistic and significance level % from fish and mobile epifauna community comparisons between samples within the OWF site and samples from control locations to the east and west of the OWF. * indicates significant differences between communities.

Site comparison	R Statistic	(Significance Level %)
control far west, windfarm	0.482	(0.01*)
control west, windfarm	0.419	(0.04*)
control east, windfarm	0.102	(11.8).
control far west, control west	0.238	(0.5*)
control far west, control east	0.54	(0.02*)
control west, control east	0.398	(0.04*)

ii) Species contributing to dissimilarity between locations (SIMPER)

The species contributing to the separation in communities identified within the ANOSIM tests included whiting (*Merlangius merlangus*), Echinoderm species, (*Asterius rubens*, Ophiuroidea) and the hermit crab (*Pagarus bernhardus*). These species displayed greater average abundance within the OWF sample sites, compared to western control sites. Flatfish species (Pleuronectidae) continued, as in post-construction beam trawl surveys in 2005 and 2006 to display the opposite trend. In 2011 Pleuronectidae influenced differences between communities with higher average abundance in control sample sites to the west of the OWF site (Table 4.15).

Table 4.15. Comparison of the most important species contributing to dissimilarity between fish and epifauna species communities at control locations and North Hoyle OWF. ↑ indicates mean √ transformed abundance increases in reference to the OWF data. ↓ indicates mean √ transformed abundance decreases in reference to the OWF data.

Species	Contribution to dissimilarity % OWF, control east	Contribution to dissimilarity % OWF, control west	Contribution to dissimilarity % OWF, control far west
Merlingius merlangus	20.9 ↑	23.56 ↓	16.65 ↓
Asterias rubens	15.8 ↓	11.19 ↓	11.59 ↓
Ophiura spp.	14.72 ↑	17.5 ↓	11.55 ↓
Echiichthys vipera	13.51 ↑	7.74 ↓	
Pagurus bernhardus	10.07 ↓	10.25 ↓	9.89 ↓
Liocarcinus spp.	7.62 ↓		8.25 ↓
Pleuronectidae		11.79 ↑	20.83 ↑
Average dissimilarity	37.25%	45.30%	49.93%

The combination of variables best describing the pattern of species communities across sample sites were distance from the mouth of the river Dee and temperature (normalised variables, *BEST*, Spearman rank = 0.305). Due to the delay in surveying the far west control sites the *BEST* procedure was also performed with temperature data removed as there was a noticeable seasonal reduction in temperature on later samples, two weeks after the initial survey. Without temperature data, the combination of distance and salinity provided the highest correlation (Spearman rank = 0.290). Estimated sediment type was excluded from the BEST procedure above (as data was a visual estimate). With estimated sediment included, salinity and distance still provided the highest correlation with species community structure (Spearman rank = 0.290), distance alone the second highest correlation (0.284) and a combination of sediment, salinity and distance the third highest (0.256). Limitations of visual sediment type estimation from video samples must be acknowledged when interpreting these results.

4.5. Discussion

This section discusses findings of analyses of sediment, benthic infauna, epifauna and fish data collected for North Hoyle OWF FEPA monitoring requirements, and analysis of data collected by BRUV, 8 years post-construction. Results are summarised then discussed in relation to before and after changes, and in relation to MPA benefits. Remaining weaknesses in survey and monitoring design, to separate development effects from natural variation and opportunities for improving evidence of ecological effects of OWF are identified. Following a summary of main results, changes in, i) sediment grain size and infauna communities, ii) 2m trawl samples of benthic epifauna and demersal fish communities and, iii) follow-up BRUV samples of mobile epifauna and fish communities are discussed under separate sub-headings. All findings are summarised in relation to MPA requirements and further research priorities are identified in a table at the end of the discussion (Table 4.16).

The hypotheses examined was that; '*presence of an OWF will increase fauna diversity and abundance within OWF sites.'* The null hypothesis tested was that; *'presence of an OWF will not change fauna diversity and abundance within OWF sites, i.e. no change will be seen from exiting baseline data and identified natural trends.'*

Summary of results:

Benthic infauna, epifauna and fish communities within the OWF displayed changes from their pre-construction state during construction and in subsequent post-construction years. Natural variation in the North Hoyle region appeared high, especially for sediment mean grain size and benthic infauna. Significant changes in sediment grain size across the survey region between years explained some of the spatial and temporal pattern in infauna communities. Environmental conditions, particularly strong tidal currents, highly mobile and spatially heterogeneous sediments and the presence of a large estuary to the south west appear to influence species communities. Results indicate the presence of OWF monopiles is likely to increase existing heterogeneity of substratum and increase opportunities for scavenging species.

The original ES noted that the development area (OWF array) consisted of coarser sands and gravels than control samples to the south and east, which contained medium sands (Innogy 2002). Sediments within the OWF array continued to be coarser than surrounding control samples, with grain size increasing further post-construction, particularly at the sample sites adjacent to a single monopile. The limited period of baseline monitoring data collection reduced confidence in separation of natural conditions from effects of the presence of the OWF. The presence of increased coarser sediments at sample sites surrounding a monopile suggests drilling, piling and later scour from presence of a monopile influence sediment grain size and associated infauna. Without samples at further monopiles, confidence in this assessment for the monopile footprint is limited. Only one year of baseline sampling also limits assessment of effects of development within the footprint of the OWF array in comparison with the wider North Hoyle bank and Liverpool Bay region, particularly as natural variation is high.

BRUV surveys eight years post-construction indicated mobile epifauna and fish communities remained similar to those present two to three years post-construction. In 2011 only communities at reference locations to the west of the OWF were similar to those recorded in pre-construction samples. The environmental variables; salinity and distance of sample sites from the nearest estuary mouth influenced species communities more than depth in 2011.

Results did not display significant increased abundance and diversity of fish and epifauna that had been suggested as a possibility by early reviews (Gill 2005; Inger et al. 2009; Linley et al. 2007, 2008). In this study there was limited evidence for potential 'spill over' of mobile species to surrounding areas (DeMartini 1993; McClanahan and Mangi 2000). In part, limited increased abundance within the OWF array is attributed to the collection of samples for all epifauna and fish data sets at distances from monopiles. Existing studies reporting high abundance of colonising epifauna and fish species had addressed the monopile footprint (Andersson and Ohman, 2010; Inger et al. 2009; Linley et al. 2007, 2008; Wilhelmsson et al. 2006). However, the data available in this study were able to examine if there had been a change, or no change in species communities due to the deterrence to fishing activity within the wider OWF array, and the increase of hard substratum present within the site (Blyth-Skyrme 2010; Inger et al. 2009; Linley et al. 2007, 2008).

High abundance of whiting (*Merlangius merlangus)* was identified inside the OWF. This species occurred in high abundance across all locations, before and after construction and is known to utilise the region as a nursery ground (Coull et al. 1998; Ellis et al. 2012). The presence of the OWF did not appear to impact this nursery ground and colonising epifauna potentially provided a food resource (Bunker et al. 2004, Reubens et al. 2013). Broadly the results do show similar trends in species occurrence and abundance to long term monitoring studies at Danish, Belgium, Dutch and Swedish OWFs which also used sample sites at a distance from monopiles (Wilhelmsson et al. 2006a; Winter et al. 2010; Lindeboon et al. 2011; Stenberg et al. 2011; Bergstrom et al. 2012). In these studies, as in the results from North Hoyle, samples within the OWF but at a distance from monopiles have either similar fauna abundance or decreased abundance in comparison to pre-construction conditions and reference sites outside the OWF. Increased fauna abundance in comparative studies was observed for specific reef associated species, but only in the direct vicinity of turbine bases and scour protection (Wilhelmsson et al. 2006a; Winter et al. 2010; Lindeboon et al. 2011; Stenberg et al. 2011; Bergstrom et al. 2012).

Discussion of results from analysis of FEPA monitoring data sets and follow up BRUV surveys.

i) Sediment grain size and infauna

Distance categories were used to further examine changes observed in infauna FEPA monitoring samples post-construction. Analyses of distance categories displayed significant differences evolved post-construction. Infauna communities from sample sites within the OWF array (including samples from 3 sites adjacent to a monopile) became increasingly dissimilar to samples across all distance categories from the array post-construction. In pre-construction samples dissimilarity only occurred between the communities within the OWF array and the furthest distance category, this dissimilarity increased post-construction.

Interaction of benthic infauna communities and sediment grain size were investigated to address weaknesses identified in the initial monitoring for assessment of MPA benefits. Sediment grain size displayed increases post-construction within the array, particularly at sample sites adjacent to a monopile, providing the most direct possible cause of these changes. Patterns in mean grain size showed a weak positive correlation to patterns in infauna species communities across all sample sites. No scour protection was present at pilings, although, construction records suggest some scour protection between 10mm and 300mm may be present at the point cables passed into the sea bed beside each turbine (Ottensen Hansen 2005). The presence of this material should be considered in the following discussion but is expected to be within too small an area to affect all sample sites near monopiles.

The results agree with the issue raised in the environmental statement, that: '*coarser sediment would be exposed at monopile bases due to construction activities and scourin*g. (Innogy 2002)' Smaller sediment grain sizes at sampling points further from turbines suggests that, away from monopile bases, changes are within natural variation. Within the study region sediment characteristics are dynamic and spatially heterogeneous, with highly mobile sediment ranging from fine sands to coarse gravels recorded in pre-construction samples (Innogy 2002; RWEnpower 2006). The FEPA monitoring sampling design limited further separation of changes within the footprint of single monopiles and the footprint of the array as a whole, due to the limited number of sample sites in each category and the limited time series of monitoring, with only one year base line and 2-3 years post-construction data. The increase in coarser sediment at the base of monopiles is deserving of more detailed study, including further years data collection, to identify the community changes over a longer time period in relation to natural variation.

Coarser sediments were also present close (<5m) to FINO 1, a German offshore research platform with four piles, similar to OWF monopiles. Re-suspension of finer mobile sands away from the foundation was suggested with settlement of coarse, dead shells, close by due to changes in local current speeds (Hiscock et al. 2002, Schroder et al. 2006). Coarse sediments are identified to drain fast and not retain organic matter, providing inhospitable conditions for colonisation of infauna (Gray 1981; Gray et al. 1990; Gray and Elliott 2009). Without the addition of rock scour protection to increase habitat complexity (Inger et al. 2009; Wilson et al. 2010) coarse sediment at monopile bases may limit the positive effect on biodiversity within the monopile and scour footprint noted in studies of OWFs with scour protection present (Wilhelmsson et al. 2006; Andersson and Ohman 2010). Although epifauna colonising the monopiles at North Hoyle OWF are likely to increase food resources for some species (such as gadoid fishes) (Langhamer 2010; Coates et al. 2013; Bunker et al.

2004; Reubens et al. 2011), deposition or exposure of coarser sediments within proximity to the base of a monopile may limit biodiversity and available prey resources in comparison to pre-existing substratum (Gray 1981).

A study of infauna communities adjacent to OWF gravity base foundations, collecting samples in four directions and between 2 and 200 metres from turbine gravity bases was conducted by Coates et al. (2013). Fine to medium sands and increased infauna biomass occurred at the closest sampling stations to the base, in the lee of the main tidal current (Coates et al. 2013). Although these foundations were larger, (23.5m diameter, extending to 55.5m including scour protection) and likely to have different influences on existing tidal currents, adapting the survey design applied by Coates et al. (2013) and completing surveys over multiple baseline years and post-construction years to investigate effects at the scale of turbine footprints is recommended. Using sample sites at graduating distances across four directions provides comparisons in reference to the path of dominant currents. This design allows identification of detailed patterns in grain size and infauna communities, which the monitoring at North Hoyle did not allow (with only 3 samples conducted in the direction of the dominant tidal current) (RWEnpower 2004, 2006; Coates et al. 2013).

Such survey designs could also be adapted to examine array scale effects and effects at graduating distances from the array, using a similar design, extending in multiple directions up to far control sites, well beyond the region of development (multiple kilometres). This survey design has been long-established in relation to examining pollution impacts on benthic communities for the oil and gas industry and could be easily adapted to marine renewable energy industry license requirements (Gray 1981; Gray et al. 1990; Gray and Elliott 2009). A best practice sampling design has been identified by Gray (1981) to include; (1) identification of key infauna indicator species within regional communities that respond to effects (such as increase or decrease in grain size); (2) extended sampling over many years but not necessarily at as many sample points; (3) collection of samples during seasons when larvae are not abundant and population densities are low, and; (4) collection of as many explanatory environmental variables as possible. Adaptation of this sampling methodology would aid future separation of OWF monopile and OWF array scale effects from natural variation and limit the weaknesses identified in this study.

ii) Epifauna and fish from FEPA monitoring (2m beam trawl)

Reports from monitoring of epifauna and fish in relation to FEPA license requirements also observed changes in species distribution (RWEnpower, 2006). Distribution and abundance of some of the most abundant epifauna species were noted to have changed during the survey period (RWEnpower, 2006). Similar noticeable changes occurred for fish species with reductions in elasmobranch occurrence in the OWF array and reduction in two dominant flatfish species across the survey region post-construction (RWEnpower, 2006). The pre to post-construction trend observed in the monitoring reports displayed similarity in species communities across all sampling sites pre-construction, to separation between communities in the OWF array sites and control sites to the east, from those to the west and north. Multivariate analyses of species communities inside and outside the array over pre and post-construction samples (PERMANOVA) indicated the presence of the OWF had affected epifauna and fish communities. However, the limited sample size in each control location and within the OWF array prevented individual ANOVA tests identifying significant dissimilarity between samples from inside the OWF array, and each control location, within each year. ANOVA R values increased for all inside OWF /outside OWF comparisons post-construction (from low pre-construction dissimilarity, R values), suggesting increasing separation between inside / outside species communities, regardless of control location, east or west.

The reduction of flatfish species, identified as contributing to differences between the species communities between pre and post-construction samples in inside and outside locations, may relate to changes in sediment grain size and prey availability within the region (Gibson and Robb 2000; Stoner and Ottmar 2003), or wider environmental or anthropogenic pressures. Flatfish require suitable sediment to bury in to avoid predators and locate preferred prey (Gibson and Robb 2000). Gibson and Robb (2000) identified juvenile plaice (*Pleuronectes platessa*) consistently selected the finest of four sediments in laboratory experiments (after 24 h, both in the light and the dark). In tagging and telemetry studies conducted at a Dutch OWF, tagged sole (*Solea solea*) were not identified by receptors on monopiles, although tagged cod (*Gadus morhua*) were identified in close proximity up to six months later (Winter et al. 2010). A small number of tagged sole were, however, returned from sandbank habitats up to 200km away (Winter et al. 2010). Neuman & Able (1998) demonstrated that sediment selectivity of the flatfish, *Scophthalmus aquosus* only decreased in the absence of food. If preferred prey are available in suitable habitat with finer sediment size, flatfish species occurring in Liverpool Bay may be less likely to extend their foraging into habitats with less suitable grain size.

Polychaetes are typical prey species recorded from stomach analysis of plaice in inshore sandbank regions of the Irish Sea and UK waters (Amezcua et al. 2003; Beare et al. 2010). Many polychaete species in pre-construction assemblages decreased in abundance post-construction within the North Hoyle OWF. The bivalve mollusc *Donax vittatus* and the polychaetes; *Nephys cirrosa* and *Magelona johnstoni,* all of which favour mobile fine sand (Southwald 1957; Desroy et al. 2002; Degraer et al. 2006) increased in abundance in control location samples. *M. johnstoni* in particular is an important prey item to plaice and other flatfish, benefitting fish still utilising habitat outside the OWF. Increased abundance of epifauna colonising turbines may have provided food sources for other species such as juvenile whiting, (*Merlangius merlangus*) observed feeding on turbines at North Hoyle OWF by Bunker (2004), and the abundance of juvenile whiting recorded in 2011 BRUV surveys.

Gadoid fish may benefit from OWF piling presence and associated food resources while pre-existing fine sediment habitats and associated food resources are favoured by flatfish. The presence of dab (*Limanda limanda*), but significant decreases of sole (*Solea solea*) and plaice (*Pleuronectes platessa*) in post-construction samples, both inside and outside the OWF may be due to anthropogenic effects or long term cycles. However, monitoring at an annual stock survey site, 6km north east of North Hoyle OWF continued to record presence of these species post-construction. The inshore Liverpool Bay region is an important spawning and nursery ground for plaice and sole (Coull et al. 1997) and the reduction in abundance inshore requires further investigation. The existing monitoring data and survey design are not over a sufficient spatial and temporal scale to examine patterns of post-construction decreases in abundance of these species at all survey sites. The lack of collection of sediment samples from the same locations as 2m beam trawls also limit interpretation of data.

Significantly greater abundance of the hermit crab (*Pagurus bernhardus*) and brittle star species (Ophiurids) within the OWF post-construction than in control areas may be explained by greater scavenging opportunities, due to epifauna observed colonising monopiles at North Hoyle OWF (Bunker 2004). *Pagurus bernhardus* and ophiuroids, as well as, *Asterias rubens*, *Liocarcinus holsatus* and small gadoids were identified as the main active scavengers feeding on different kinds of food, representing damaged and disturbed benthos (due to beam trawl fishing activity), deployed in traps at locations in the southern North Sea (Groenewold and Fonds 2000). Increases in abundance of these species in samples from inside the OWF array contributed to dissimilarity between trawl samples from sites inside and samples from sites outside the OWF post-construction. Greater abundance of food resources from epifauna colonising turbines and distribution in tidal currents of benthos falling from turbines are likely to influence occurrence of scavenging species (Coates et al. 2013; Reubens et al. 2013). Ellis et al. (2000) identified a separation in demersal epifauna and fish communities in Liverpool Bay and the Eastern Irish Sea related to sediment characteristics. The *Pleuronectes-limanda* assemblage, identifiable within the study area (inshore regions of Liverpool Bay) pre-construction was consistent with finer sand substratum. Offshore regions of Liverpool Bay with coarser substratum containing gravels were characterised by a *Microchirus-pagarus* community (Ellis et al. 2000). At the North Hoyle study site, the species communities post-construction maintained similarity to both these assemblages. Small areas to the north and west of the OWF also contain *Alcyonium* communities within coarse and stony grounds, with abundant hydroids, bryozoans and soft corals (*Alcyonium digitatum*) (RWEnpower 2006).

At a broad scale this suggests that OWF construction and operation has not affected the communities in the region beyond natural variation, as the communities are common in the wider region (RWEnpower 2006). When considering the relationships to MPA goals for long term protection or recovery of habitats, the change from the finer sand associated *Pleuronectes-Limanda* community, existing pre-construction, to a coarser sediment community typical of regions further offshore is important to investigate further within MPA assessment. As discussed long term baseline monitoring is required to assess the effects of development in respect to the natural patterns in substratum changes as sediments in the region are highly mobile. It is feasible also, that as communities represent those occurring within the region, if OWF pilings were removed and natural and physical processes remained the same, the site would return, in time, to pre-construction sediment distribution and associated species communities.

Despite separating control sites to further examine patterns observed in species communities, weaknesses in the survey design prevented confident separation of observed effects from natural variation. The lack of baseline data over multiple years prevents the identification of natural trends within the region. Lack of extended post-construction data beyond 2-3 years limits interpretation to identifying large, broad scale effects (relevant to FEPA license requirements). The original monitoring design addressed specific questions in the North Hoyle OWF Environmental Statement (Innogy 2002), thus, sample sites were concentrated at locations of predicted impacts (Innogy 2002). This inhibited assessment of change at monopile footprint scales and array scales, in relation to natural variation within the study site and so assessment of benefits in relation to MPA goals. Environmental statement issues and the requirements of this study to assess effects on species presence and abundance at monopiles could not be confidently assessed, as 2m beam trawl sample sites were beyond 50m from monopiles. The 2m beam trawl was sufficient for collecting epifauna samples and sampling sessile organisms such as bryozoans that characterise epifauna communities but larger, more mobile fish species could easily avoid capture (Walker et al. 2009).

More suitable methods are suggested by Walker et al. (2009) to assess fish populations. These include larger 4m beam trawls and static gill nets, visual techniques such as scuba diver surveys or remote video techniques provide methods to assess mobile epifauna as well as fish populations. A more suitable survey design for assessing fish and epifauna for this study (assessing benefits to MPA goals and investigating finer scale changes in relation to baseline conditions / natural variation) would include a combination of 2m epifauna trawls and visual surveys conducted at the same sample sites as sediment grain size, organic content and benthic infauna samples. Analyses of the existing 2m beam trawl data for this study would be improved by investigating full epifauna communities from trawl samples, and repeating the analyses with mobile species only, to then relate to the BRUV data.

Monopile footprint effects would ideally be investigated using the survey design (sample site positions) utilised by Coates et al. (2013) and Wilhelmsson et al. (2006), with samples taken at graduating distances from the structure, and along at least four directions in relation to dominant tidal currents. Array scale effects would ideally be investigated using the larger scale distance gradient sampling design across separate directions (using the same sample points as sediment and benthic infauna samples) displayed by Gray et al. (1990). Where sites within an OWF array consist of separate substratum, a stratified random design, collecting samples at different control locations, each representing the different substratum present in the impact area is required. This stratified random survey design based on substratum is provided for the 'Wave Hub' wave energy test site in North Cornwall, UK by Witt et al. (2012).

Additional stomach content analysis of fish captured within the OWF array and tagging and telemetry of key fish species in the region, such as flatfish and elasmobranchs would benefit identification of their use of habitat resources provided in the OWF (Winter et al. 2010; Reubens et al. 2011). Analyses based on fish species functional guilds, (such as habitat use/preference) would have been beneficial, particularly due to the construction of OWFs and associated hard substratum within pre-existing soft sediment habitats (Elliott and Dewailly, 2007). Pre-existing knowledge of increase of hard substratum and associated epifauna on structures, and so foraging benefits to specific fish species (Wilhelmsson et al. 2006;

Andersson and Ohman 2010; Reubens et al. 2013), combined with associated loss of soft sediment habitat presents a testable hypothesis for analysis of change in distribution of fish species with separate substratum and prey preferences (Elliott and Dewailly 1995; Elliott et al. 2007).

iii) Follow-up baited remote underwater video survey

THE BRUV survey in 2011 examined the mobile epifauna and fish community 8 years post-construction using a visual method identified to assess a greater proportion of the fish population (Walker et al. 2009; Sheehan et al. 2010; Witt et al. 2012). Weaknesses to be considered for the method include response of species to the bait used and the extent of dispersion of the olfactory trail upon tidal currents (Langlois et al. 2010; Sheehan et al. 2010). Increased sample size (at locations of 2m beam trawl sites conducted for existing monitoring) allowed for significant dissimilarity between OWF and control locations to the west of the array to be identified. Similarity between all locations, and similarity to the pre-construction species communities sampled by 2m beam trawl as part of FEPA monitoring, suggested by the null hypothesis were not evident. Only samples from control locations to the east of the OWF were not significantly dissimilar to samples within the array, with little separation of species communities. Addition of samples from a reference location at a greater distance (to the west) of the OWF array also provided identification of greater dissimilarity, over distance to the west. From the environmental variables collected for the BRUV surveys, a salinity and distance gradient from the nearest estuary mouth, situated to the south east of the OWF best explained differences in communities across sample locations.

General trends apparent in the post-construction monitoring data collected 2-3 years after construction were also identified 8 years post-construction. High abundance in the samples from within the OWF array of the scavenging species; *Pagurus bernhardus*, ophiuroids, *Asterias rubens*, *Liocarcinus holsatus* and small gadoids, (represented by high abundance of *Merlangius merlangus*) continued to contribute most to the separation in communities between samples within the array and those to the west and far west. Higher abundance of flatfish species (Pleuronectidae) in control sites to the west, particularly the far west in comparison to OWF samples and eastern control samples added to the increased dissimilarity between these locations. Although this suggested a recovery from extremely low abundance of Pleuronectidae species in existing FEPA monitoring data, abundance appears to have only increased in locations to the west of the OWF array. The similarity of communities within the OWF and eastern controls, and the presence of a distance gradient to the west (away from the Dee estuary mouth) suggest environmental conditions are influencing these changes as well as OWF presence.

Samples within the array continued to share more characteristics with the deeper, coarser sediment, Eastern Irish Sea assemblages (*Microchirus-pagarus* and *Alcyonium digitatum* assemblages) identified by Ellis et al. (2000) than the inshore, fine sand communities (*Pleuronectes-limanda* assemblages) present in pre-construction samples (RWEnpower 2006; Ellis et al. 2000). In addition the small gadoid, whiting (*Merlangius merlangus*) appeared in high abundance across all sample locations. Presence of this species in high abundance in the OWF array reflected observations from one year post-construction (Bunker 2004). This suggests continued benefit to the species from habitat provided within the OWF. Such benefit is of specific interest as the whiting is a Biodiversity Action Plan species (JNCC 2013) and the survey area is within a recognised spawning and nursery ground for the species (Coull et al. 1998; Ellis et al. 2012). The survey method, using BRUV instead of a 2m epifauna trawl is likely to have aided identification of this species in greater abundance due to the use of bait. Also, due to its mobility the species is likely to have avoided the slow moving 2m beam trawl used in original monitoring surveys (Walker et al. 2009). The increased observation of elasmobranch species (at sample sites outside the OWF array) by BRUV surveys is also likely to be influenced by these factors.

An identifiable weakness of the 2011 survey was that time and resource constraints meant sediment samples and infauna samples were not collected. The single year of follow up BRUV sampling also did not address the weakness of a lack of long term annual monitoring to identify natural trends.

In relation to co-location of OWFs within MPAs the continued identification of an, all be it, small change in species assemblages and potential relationship to alteration in distribution of sediment types (grain sizes) requires consideration on a case by case basis. Recovery appears from initial construction impacts to a similar, but altered state to pre-construction baseline conditions (Elliot et al. 2007; Duarte et al. 2014). Presence of OWF monopiles and potential habitat change are possibly acting as buffers preventing full return to pre-construction conditions (Elliot et al. 2007; Duarte et al. 2014). As identified through a systematic review certain species which can utilise the habitat and prey resources provided by the presence of OWF pilings benefit (increase in abundance) while other species show less identifiable benefit or decrease in abundance at the site. Specific highly mobile fish species: Pleuronectidae and elasmobranchs, including Thornback ray (*Raja clavata*) were recorded to reduce in abundance or were not recorded within the OWF array following construction (RWEnpower 2006). These species continued to appear in lower abundance in the OWF site in BRUV samples or were not recorded in any sample site inside or outside the array (e.g. Thornback ray, *Raja clavata*). In addition to changes in available habitat and prey resources, operational noise and EMF have been raised as potentially having a negative impact on abundance of fish within OWF development regions (Thomsen et al. 2006; Inger et al. 2009). Although these factors were not directly investigated in this study they are discussed in more detail in the following sub sections as factors deserving further investigation in relation to co-location of OWF within MPAs.

4.5.2 Noise disturbance

Pile driving and operational noise from turbine monopiles are important areas for consideration in relation to changes in presence and abundance of fish species observed at North Hoyle OWF. Turbine construction and deployment took place between April and July 2003 (RWE npower 2005). Noise levels during North Hoyle OWF pile driving reached a maximum of 262 dB, dB (p-p) re 1 μPa at 1m for 10 m water depth (Nedwell et al. 2003). The energy created by pile driving at North Hoyle OWF was generally around 200 Hz, with additional peaks at 800 Hz and 1.6 kHz (Nedwell et al. 2003). Cod and herring can perceive noise in this range at 80 kilometres and have been shown to swim away from the source of noise at distances of 1km, flatfish such as dab (*Limanda limanda*) however display less sensitivity to sound (Thomsen et al. 2006, Anderssen, 2011). Sensitivity to noise disturbance in fish species is greater in species with swim bladders (such as cod and herring) (Thomsen et al. 2006, Anderssen, 2011). The presence of abundant whiting (a gadoid with a swim bladder) in the array while the OWF was operational in 2004 (Bunker, 2004) and in 2011 suggests operational noise is not affecting this species. Piling and construction noise however is loud enough to have an effect during construction periods, potentially affecting spawning. Sediment, disturbance from drilling and piling activity, rather than noise, is more likely to affect demersal flatfish species (Pleuronectidae), as they do not possess a swim bladder.

Between 2003 and 2011 two other similar OWFs were constructed in Liverpool Bay. Further noise and sediment disturbance would therefore relate to the pile driving at Burbo Bank (8km to the east of North Hoyle) in July 2006 (Nedwell et al. 2007) and Rhyl Flats 6km to the west of North Hoyle during April to August 2008 (Hull et al. 2011). Ecological effects of construction activity are important considerations in assessing MPA benefits in a region with multiple planned OWF developments. It has been proposed that pile driving due to construction of Scroby Sands OWF off the coast of Norfolk has led to mass mortality or displacement of herring *(Clupea harengus).* This may have also led to poor foraging success and increased nest abandonment within an internationally important local colony of the Little tern *(Sternula albifrons)* (Perrow et al. 2011). Mitigation, such as use of bubble curtains surrounding piling sites to limit noise, as well as existing approaches of avoiding piling during known spawning times may aid reduction of potential impacts (Hawkins et al. 2006).

4.5.3 Electric and magnetic fields

The effect on fish of electrical and magnetic fields (EMF) emitted from an array of undersea cables within an OWF is still a developing area of knowledge (Gill et al. 2012). The subsea cables used are sheathed. Sheathing will prevent the primary electrical (E) field from entering the water column. However, sheathing cannot prevent the magnetic (B) field generated by the E field from entering the surrounding water column. The B field will also generate an induced electrical field outside the cable (Gill et al. 2005). EMF generated by cables within the OWF could be a continuing factor to the lack of abundance of flatfish and elasmobranchs within the array and near control sites compared with pre-construction conditions.

Magnetic fields generated by the cables at OWFs in the Swedish Baltic have been linked to changes in swimming patterns of migratory eels (*A. anguilla)* within 500 metres of cables (Ohman et al. 2007, Westerberg and Lagenfelt 2008). Direct studies on sensitivity of flatfish species' electroreception appear limited, however extended migrations within tidal streams are likely to utilise geophysical clues, particularly magnetic fields (Metcalfe et al. 1993, 2006; Braithwaite and Perera 2006). The magnetic fields detectable by those marine organisms that use the earth's magnetic field for migration are considered to be in the range of 10 - 50 µT (Walker et al. 2002). Normandeau et al. (2012) state the average magnetic B field on the surface of a standard subsea AC cable to be 7.85 µT. Modelling of the B field produced by a 170 Ampere current produced a B field of 20 µT and an iE field of 61.5µV/m. (Gill et al. 2009). Modelled simulations of a 700 Ampere current provided B fields at the cable surface of 40 µT (CMACS 2005). Field measurements of the E field close to the main subsea cable at North Hoyle OWF were 110 µV/m (Gill et al. 2009). The North Hoyle OWF cable is therefore likely to produce a larger magnetic (B) field, well within the detectable range of species using the earth's magnetic field for migration.

Gill et al. (2009) used microcosm experiments to study the effects of slightly lower EMFs than those generated by OWF subsea cables on elasmobranch species, thornback ray *(Raja clavata)* and catshark (*Scyliorhinus canicular*). These experiments showed increased general movement (rays) and movement to the cable (catshark) when the cable was turned on, suggesting the EMFs generated by the cable are detectable to these species. As the microcosm limited the distance the elasmobranchs could travel, a specific attraction or avoidance response at the scale of a full OWF array remains untested. The cumulative effect of multiple cables and arrays is, at present, unresolved and the behavioural response of fish populations at a regional scale requires further study.

Modelling of the electrical fields produced by cables buried to 1 metre at North Hoyle indicated fields generated to be 91 µV/m. Verification by field measurements revealed a magnetic field of 110 µV/m which lies at the border between a field that would be expected to attract elasmobranches (<100 µV/m) and that which would be expected to repel them (>100 µV/m) (Gill et al. 2005; Gill et al. 2009). Field tests at North Hoyle showed decay to half this value (50 µV/m) at 150 metres from the cable (Gill et al. 2009). As detection of magnetic and electric fields by flatfish is poorly understood and attraction and repulsion levels are not available further studies are required to elucidate the effects of cables. Metcalfe et al. (1993) suggest that plaice (*Pleuronectes platessa*) may be able to detect the electrical field induced by the interaction of peak tidal streams with the earth's geomagnetic field. This would require sensitivity to electrical fields within the range of 8-25 µV/m (Barber & Deacon, 1948; Pals et al. 1982; Gill et al. 2012). These values are well below the modelled field emitted at the surface by a cable buried to 1 metre and the recorded field up to 150 metres away. Interference to the fish's magnetic or electrical reception may alter movement patterns and inhibit foraging success, (Ohman et al. 2007; Viswanathan 2010). Further understanding of how these electro-sensitive and migratory species are effected by EMF at the scale of OWF developments is required to fully examine MPA benefits. Tagging and telemetry experiments offer an opportunity to investigate this by examining movement patterns of these species in locations containing OWFs (Winter et al. 2010).

Table 4.16 Summary of findings and confidence in effects identified in relation to co-location of OWFs within MPAs. (Further research requirements are also identified).

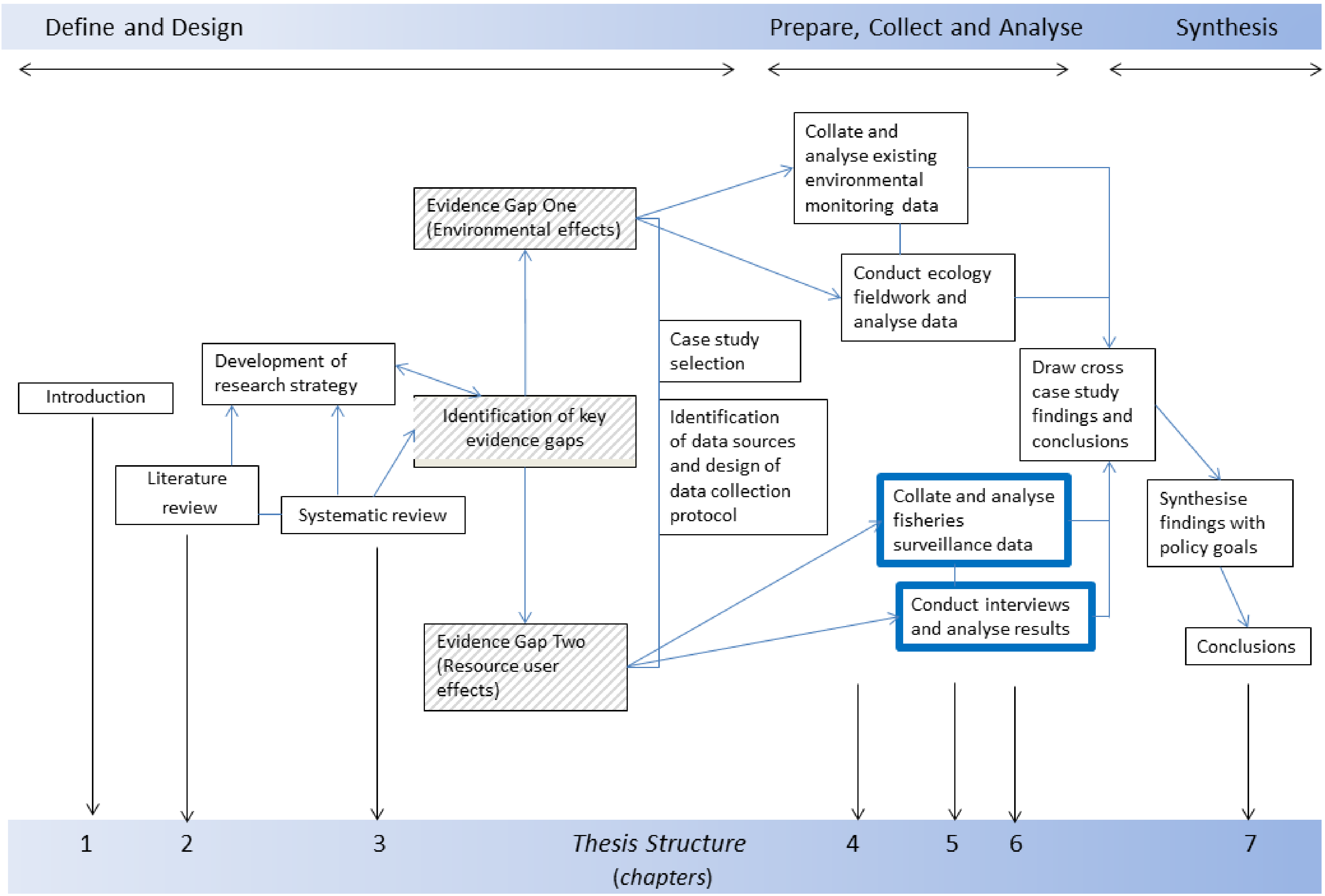
Findings / Effects	Supporting studies	Confidence of effect/evidence (signal and noise)	Change natural or anthropogenic	MPA co-location benefit / disadvantage (repurcussions)	Mitigation	Research priorities
●Increase in coarser sediment	Belgium (Coates et al., 2013) Germany (Schroder et al., 2006)	Only confidently attributed to sample sites adjacent to a monopile, within the dominant current direction at NHOWF.	▪ **Natural** - Change over the footprint of the whole array is within natural conditions. ▪**Anthropogenic** effect within the monopile footprint. ▪Presence of monopiles may increase rate of change in an environment with pre-existing highly mobile sediment. .	▪Coarser sediments drain fast and do not retain organic matter, providing inhospitable conditions for colonisation of infauna (Gray 1981). ▪Potential to alter sandbank habitats at monopile footprint scales may impact MPA objectives to preserve natural habitats.	▪Mitigation such as use of rock scour protection may increase biodiversity at the base of monopiles and limit disruption to surrounding sediment (Coates et al., 2013; Wilhelmsson et al, 2006; Langhamer and Wilhelmsson 2009; Wilson et al., 2010).	▪Monitoirng would be improved by addressing monopile footprint effects, using more detailed sampling methodologies applied by Coates et al., (2013). ▪Seperation of development and natural effects would be aided by extended baseline monitoring and continuation of post-construction monitoring over multiple years (Walker et al., 2009; Gray 1981).
●Increase in scavenging species. ●Community post-contruction closer to assemblages typically seen further offshore on coarser sediment than in inshore areas.	UK North Sea (Groenewold and Fonds 2000), UK Irish Sea (Ellis et al., 2000)	▪Change in species presence occurred within the NHOWF following construction (2-3 years) and was still identified in 2011 BRUV surveys 8 years post-construction. ▪A very similar species presence occurred at control sites to the east of the OWF in 2011, suggesting wider environmental conditions also influenced change in communities between pre and post-construction samples.	▪**Natural** - Coarser sediment and communities associated with this habitat type were pre-existing in the region. ▪**Anthropogenic** - The presence of monopiles and interaction with tidal currents is likely to have increased already dynamic conditions within highly mobile sediments. ▪Additional prey available from epifauna on pilings.	▪As for increase in coarser sediment, individual species benefits (species that are increasing in presence and abundance) require assessment in relation to individual MPA objectives. ▪For instance, the Gadoid fish, whiting (*Merlangius merlangus*), is of conservation interest as a Biodiversity Action Plan species (JNCC 2013).	As above, mitigation such as use of rock scour protection may increase biodiversity at the base of monopiles and limit disruption to surrounding sediment (Coates et al., 2013; Wilhelmsson et al, 2006; Langhamer and Wilhelmsson 2009; Wilson et al., 2010).	▪Extended baseline monitoring to provide data on pre existing natural variation at OWF sites ▪Sampling at graduating distances from the OWF array in all directions would aid assesment of the extent of effects, and a greater view of regional conditions.

Findings / Effects	Literature	Confidence level	Change natural or anthropogenic	MPA benefit / dis adv.	Mitigation	Research priorities
●Decrease in flatfish abundance	Denmark (Stenberg et al., 2011), Netherlands (Winter et al., 2010)	▪A significant decrease was seen before and after construction but at both development and control locations, suggesting a regional pattern. ▪In follow up BRUV surveys a significant decrease in abundance was seen in the OWF, compared to the control sites to the west, suggesting factors within the OWF habitat may influence flatfish abundance. ▪Confidence was limited for monitoring due to limited baseline data because BRUV follow-up surveys were onlyconducted over a single year.	▪**Natural -** decrease in certain species; sole and plaice, appears to have occurred across the region. ▪**Anthropogenic** - 8 years post-construction habitat outside the OWF appears of greater benefit to flatfish species. ▪Seperation of sediment and infauna community changes within the OWF from natural variation are required to relate if distribution changes are due to the presence of the OWF or a result of regional, dynamic mobile sediment characteristics.	▪Existing studies as well as the findings at NHOWF suggest flatfish species show limited benefit from presence of OWF pilings. ▪This species specific response may be a disadvantage to objectives of certain MPAs.	▪Mitigation may be limited to approaches discussed to reduce disturbance to sediments at greater distances from monopiles (use of appropriatly designed scour protection)	▪Improvements to survey design for examining changes in sediment, infauna and epifauna, ▪Telemetry and tracking methods to examine movement of flatfish species in relation to OWF sites and stomach content analysis in relation to prey species available within the OWF and at control sites would aid investigation of changes in flatfish distribution.
●Decrease in elasmobranch abundance	(Gill et al., 2005, Gill et al., 2009)	▪Limited individuals were present in the OWF pre-construction but none were recorded in the OWF array post construction. Confidecne in initial monitoring was limited due to the use of a 2m beam trawl. ▪In follow up studies presence in the OWF array remained very rare (3 individuals across all samples). Again confidence limited due to only one years data collection.	▪**Natural** - Suitability of substratum, presence or prey and thorough assessment of baseline abundance are lacking. ▪**Anthropogenic** - Greater abundane in controls suggests there may be an effect from the OWF. Limited confidence due to initial use of 2m beam trawl and then only one year follow up with BRUV highlights a need for further investigation.	▪Further investigation is required, ideally with tagging and telemetry to establish use of habitat within the OWF site (pre and post construction).	▪ Evidence of attraction or avoidance from OWF and evidence of use of habitat within OWF required to identify MPA benefit or disadvantage. ▪Potential mitigation includes greater sheathing of cables. ▪ Use of rock scour protection to increase diversity of habitats and prey resources.	▪Tagging and telemetry experiments on key elasmobranch species at OWF site such as Thornback ray (*Raja clavata*) (pre and post-construction).
●High abundance of whiting *(Merlingius merlangus)*	Bunker 2004; Reubens et al., 2013; Fowler et al., 1998; Lokkeborg et al., 2002; Fabi et al., 2002; Karlson 2011; Hunter et al., 2009)	▪Results provided confidence that the presence of OWF monopiles did not negatively affect whiting abundance and possibly benefitted the species. ▪Whiting were identified feeding at monopiles in large numbers post construction (Bunker 2004) and were recorded in high abundance in the 2011 BRUV survey. Whiting were also recorded in high abundance across the region.	▪ **Natural** - High abundance regionally is likely to be related to natural conditions. ▪ **Anthropogenic** - The presence of OWF monopiles provides an additional food resource that may aid maintainance of regional abundance and limit mortality as bycatch, if fishing activity limited within the OWF (Lockwood 2005).	▪Benefit to this Biodiversity Action Plan species (JNCC 2013)	▪Not required although use of scour protection such as complex larger rocks may further increase benefits (Hunter, 2009; Wilson et al., 2010)	▪ Visual diver or remote video surveys of fish species associated with monopiles and associated footprints would be beneficial, using survey designs applied by Wilhelmsson et al., 2006; Andersson and Ohman 2010).

○→● *4.6 Summary*

- Species positives and negatives have been identified through the meta-analyses in chapter 3. Further evidence for these trends has been identified in this case study of the ecological effects of North Hoyle OWF.
- These trends suggest potential for long lasting change to habitat and communities in OWF sites with associated ecological benefits to certain species and disadvantages to others.
- Benefit of these effects to MPA requirements will depend on goals of individual MPAs and regional MPA networks.

The social and economic effects of changes in habitat, species presence and abundance will also affect the achievement of MPA goals, particularly in relation to the UKs MCZ network. A primary resource user such as the local fishing industry operating in OWF development regions will provide an indication of species and ecological changes, through changes in activity and catches before and after OWF development. The following chapters will aim to identify if changes in activity and catches have occurred for different fishing fleets (gear types, grouped as static gears such as set nets and traps and mobile gears such as towed trawls and dredges) in relation to OWF sites. The social and economic effects of OWF development and the effects of any changes experienced are assessed through interviews with fishermen. Evidence on both the ecological and economic effects of changes in fishing activity will be relevant to attaining regional MCZ network goals and successful regional marine plans.


Define and Design
Prepare, Collect and Analyse
Synthesis
Collate and analyse existing environmental monitoring data
Evidence Gap One (Environmental effects)
Conduct ecology fieldwork and analyse data
Case study selection
Development of research strategy
Draw cross case study findings and conclusions
Introduction
Identification of key evidence gaps
Identification of data sources and design of data collection protocol
Literature review
Systematic review
Collate and analyse fisheries surveillance data
Synthesise findings with policy goals
Conduct interviews and analyse results
Evidence Gap Two (Resource user effects)
Conclusions
1
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Thesis Structure
(chapters)
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7

Chapter 5. Resource User Effects

The effects of OWFs on fishing effort and landings

5.1 Introduction

Offshore wind farms (OWFs) are being rapidly developed in the UK and neighbouring European states. Further developments are planned across Europe and globally as a primary means of generating electricity with reduced carbon emissions and to decrease reliance on fossil fuels (EC 2013; 4C offshore 2013). Marine protected areas (MPAs) are also being designated across Europe to maintain or restore habitats and wild species as required by the EC Habitats Directive 1992 (JNCC, 2013, 2014). Marine renewable energy (MRE) development and the designation of marine protected areas will inevitably restrict space available for fishing and other activities. The co-location of OWFs with MPAs may provide a means of limiting the area closed to fishing activities, while augmenting stocks of commercial species. Alternatively OWFs may provide new fishing opportunities to mitigate for area closures through MPAs and disruption to fishing activity during construction activities for OWF (Linley et al. 2008; Inger et al. 2009).

The limitations to fishing activity, particularly mobile (towed) gear to avoid entanglement with OWF infrastructure has been identified as potentially creating *de facto* exclusion zones, effectively acting as MPAs to most fisheries (Inger et al. 2009). Globally MPAs have been shown to increase fish biomass (Gell and Roberts 2003; Halpern 2003; Stewart et al. 2008; Russ et al. 2009). In certain examples this has led to increased catches of commercial fish including beneficial lobster catches adjacent to reserves in New Zealand and Florida, USA (Kelly et al. 2000, 2002; Suman et al. 1999), seabream catches in South Africa (Cowley

2002), scallop and yellow tail flounder in the north west Atlantic (Murakawski et al. 2000, 2005; Cadrin 2000) as well as a variety of Caribbean reef fish in St Lucia (Roberts et al. 2001; Gell and Roberts 2003). Artificial reefs have also led to increased species biomass at sites including commercially targeted fish species as well as lobster and edible crab (Jenson 2000; Hunter and Sayer 2009).

At specific wave energy device test sites and OWF sites in Europe, similar beneficial effects have been recorded, with commercially important species occurring in association with MRE structures (Langhamer and Wilhelmsson 2009; Reubens et al. 2010, 2013; Winter et al. 2010, Stenberg et al. 2011; Bergstrom et al. 2012). The additional availability of hard surfaces, in particular complex stone or boulder habitat scour protection or concrete bases with holes has been shown to increase abundance of specific commercial crustaceans and smaller non-commercial reef associated fish (Wilhelmsson et al. 2006a; Langhamer and Wilhelmsson 2009; Andersson et al. 2009). Environmental monitoring reports from Horns Rev OWF in Denmark, Egmond an Zee OWF in the Netherlands and Lillgrund OWFs in Sweden provide evidence of these benefits extending to larger commercial fish species (Winter et al. 2010; Lindeboon 2011, Stenberg et al. 2011; Bergstrom et al. 2012). In the North Hoyle case study in chapter 4, sampling methods limited identification of commercial fish abundance within the monopile footprint. The high abundance of the gadoid, whiting *Merlangius merlangus* within the OWF array suggests this trend may be seen at UK OWFs. The potential benefit of monopiles as a food and shelter resource to juvenile whiting, observed by Bunker (2004) may indicate production as well as attraction (Bohnsack 1989).

Higher densities of fish found associated with reef structures and OWF pilings may be due to habitat limitation previously limiting the regional population (Alevizon and Gorham 1989; Bohnsack 1989). The species showing increased abundance in relation to OWF structures may indicate a production effect occurring in relation to the additional habitat and food resources provided, in addition to simply behavioural attraction (Bohnsack 1989; Pickering and Whitmarsh 1997; Bortone 1998; Svane and Petersen 2001). Fisheries targeting these species in OWF development regions are likely to show increased catches and effort in proximity to sites, as in patterns displayed in relation to marine reserves in the North West Atlantic (Murakawski et al. 2000, 2005; Cadrin 2000), New Zealand (Kelly et al. 2000), South Africa (Cowley 2002) and the Caribbean (Roberts et al. 2001; Gell and Roberts 2003). Fisheries targeting species that showed no change in abundance, or decreased abundance within OWF sites may experience large scale loss of grounds and displacement of effort to remaining or alternative grounds.

There may also be differences in the activity patterns of mobile gear fishing fleets (using towed gear such as trawls and dredges) and static gear fishing fleets (those using fishing gear such as pots, traps and nets). When surveyed through interviews and questionnaires in 2006, when two 30 turbine OWFs were operative, mobile gear fishermen expressed concern over being able to safely fish with towed gears in proximity to turbines (Mackinson et al. 2006). Loss of ground and displacement were identified as the biggest negative impact of OWFs on fishing (Mackinson et al. 2006). Protection of nursery areas and potential for exploitation of OWF sites by static gear fishermen were identified as likely positive effects (Mackinson et al. 2006).

5.2 Aims and Objectives

This chapter aims to evaluate the effect of OWF development on fishing activity in three case study areas.

The key objectives are

1. Investigate if either effort displacement or increased fishing activity has occurred in relation to OWF sites for mobile and static gear fisheries

2. Investigate if the changes in species abundance in relation to OWFs and similar structures, identified in the previous chapters, are identifiable in spatial activity and landings from regional fisheries.

The hypotheses investigated in this chapter are: Presence of OWFs will lead to increases in catches and fishing effort in proximity to OWF sites. (Null hypothesis – Presence of OWF will not affect catches and fishing effort in proximity to OWF sites)

By approaching the key evidence gaps identified in the reviews in chapters 2 and 3 of the thesis, the results of this chapter are intended to inform potential regional ecological and economic effects of co-location of OWF and MPAs. The results are also intended to provide useful evidence to inform marine planning decisions.

5.3 Study sites

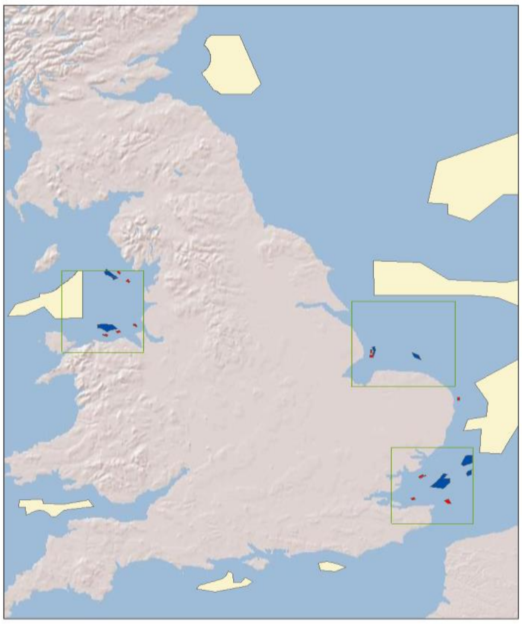


Figure 5.1. The three study sites, Liverpool Bay (North Wales and Merseyside, UK), Greater Wash (Norfolk and Lincolnshire, UK) and Greater Thames (Kent and Essex, UK). OWF developments are displayed that were operational or under construction, round one (red), round two (blue). The large round three leased areas are also displayed (yellow).

5.2.1. Liverpool Bay

The Liverpool Bay region includes the UKs first round one OWF, North Hoyle (constructed 2003) and two further operating OWFs, Burbo Bank (constructed 2006) and Rhyl Flats (constructed 2008). The larger round two OWFs (Gwynt Y Mor) began construction late in 2011 (after data had been collected for this chapter) and is due to be completed in 2014 (Figure 4.1a).

Fishing activity in Liverpool Bay has reduced over the last ten years but consists of similar fishing practices to those described by Mackinson et al. (2006). Demersal trawl fisheries for sole, plaice and skate traditionally occur in spring, summer and autumn, with smaller under 10m vessels operating otter trawls and larger over 10m vessels operating beam trawls. Only a very small number of local vessels still fish from ports such as Mersey, Hoylake, Rhyl, Ross on Sea and Conwy (Mackinson et al. 2006; North Western IFCA and Hoylake Fishermen's Association pers. comm. 2011; MMO 2012). Historically the largest local fleets operated from Fleetwood but again very few vessels are still active.

Small fleets of charter rod and line angling vessels operate out of Rhyl, Ross on Sea and Conwy targeting offshore wrecks for pollock, ling, conger and inshore areas for tope, skate, bull huss, gurnard and flatfish amongst a range of species. A small potting fishery targeting crab and lobster operates out of Conwy and a number of under 10m vessels occasionally fish inshore areas of Liverpool Bay for shrimp, as well as netting for bass. Scallop beds between Anglesey and the Isle of Man and sole, plaice and skate in Liverpool Bay have been fished by large visiting vessels from across the UK, Ireland and Belgium (Mackinson et al. 2006; North Western IFCA and Hoylake Fishermens Association pers. comm. 2011.). The region includes spawning grounds for cod, whiting, plaice and sole during winter and spring months and nursery areas for herring, whiting and plaice (Coull et al. 1998; Ellis et al. 2012).

5.2.2 Greater Wash

The round one OWFs in the Greater Wash region, Lynn and Inner Dowsing, lie almost adjacent to each other 6 kilometres off the Lincolnshire Coast and were operational in 2009. Combined, these two OWF have 54 turbines and cover 20 square kilometres (km^2). At the time of the study the round two OWFs Lincs and Sheringham Shoal were currently being constructed (completion 2013). These consist of 75 turbines over $41km^2$ and 88 turbines over $35km^2$ respectively. Beyond twelve miles offshore two more OWFs Race Bank ($62km^2$) and Dudgeon ($35km^2$) had been consented and the larger round three OWFs Triton Knoll ($390km^2$) and Hornsea ($4735km^2$) were in planning stages (Fig 5.2). Aggregate dredging also takes place in the mouth of the Wash.

The significant ports in North Norfolk and Lincolnshire have particular specialised fisheries. Boston and Kings Lynn in Lincolnshire contain fleets of vessels trawling for brown and pink shrimp and dredging for cockles in the spring and summer and dredging for mussels into the winter. The chalk reefs in the region support creel and parlour pot fisheries for brown crab, velvet crab, lobsters and whelks. These potting fisheries operate from the North Norfolk ports, Brancaster, Wells-next-the-Sea, Blakeney, Sheringham, Runton and Cromer. Some inshore static net fishing for bass and sole in spring and summer and cod and whiting in winter is also conducted on this coast (Mackinson et al. 2006; Eastern IFCA pers. comm. 2011).

This study region provides a spawning area for herring (autumn), lemon sole (spring and summer), sole (spring) and a nursery area for herring, cod, plaice, lemon sole and sole (Coull et al. 1998; Ellis et al. 2012).

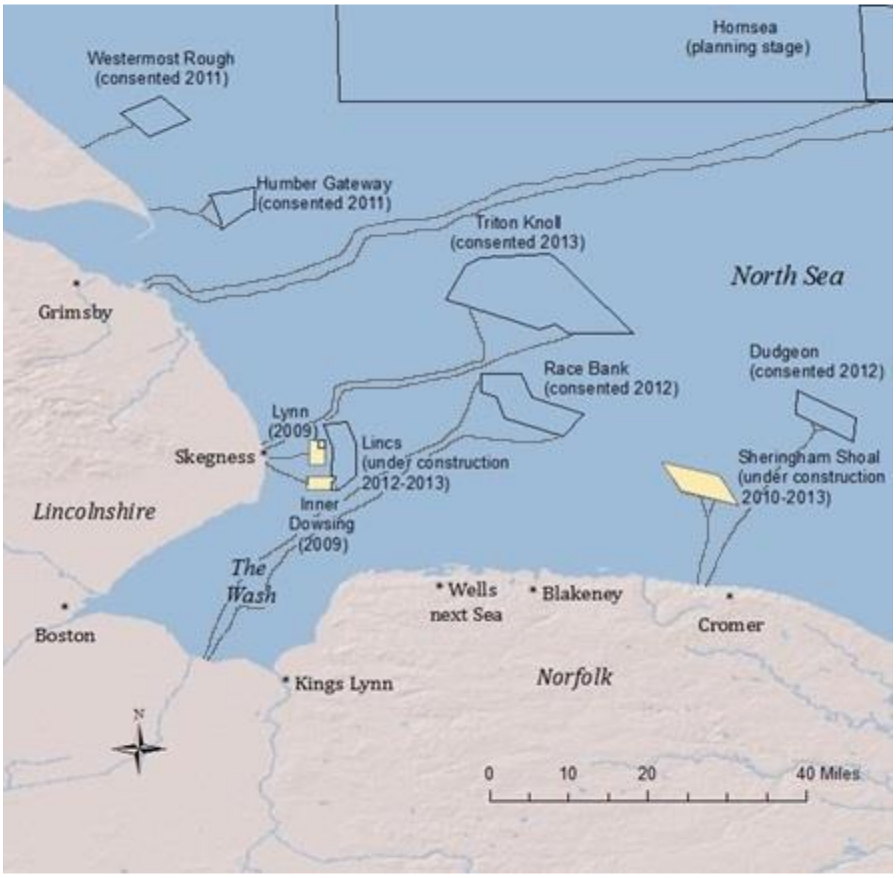


Figure 5.2 The Greater Wash study site, OWF development including cable routes at the time of the study, years in brackets refer to construction date.

5.2.3. Greater Thames

OWF development began in the Greater Thames estuary and Kent and Essex coasts in 2005 with the 30 turbine, 10 km² round one OWF, Kentish Flats operational in 2006. The larger Thanet OWF (100 turbines, 35km²) and Gunfleet sands OWF (48 turbines, 16km²) were operational in 2010. The 146km² Greater Gabbard OWF was operational in 2012 and the larger still London array OWF (175 turbines 121km²) is currently under construction. One further 146km² site, Galloper has received consent and lies approximately 12 miles offshore (Fig 4). Due to its proximity to London and densely populated urban areas this study region has been subject to previous offshore construction, particularly cable laying as well as aggregate dredging.

The Greater Thames estuary and Kent and Essex coasts support rich and diverse fisheries. Whitstable and Ramsgate in Kent and Leigh-on-Sea, West Mersea and Harwich in Essex contain fleets of smaller inshore vessels, typically under 10m which utilise drift nets and fixed nets, primarily for sole. Inshore vessels also utilise netting, demersal trawls, mid-water trawls and long lines for bass, cod, thornback ray and mullet as well as trawls and nets for brown shrimp. Potting occurs for crab, lobster and whelk and fyke netting for eels. Vessels from Whitstable in particular also work wild oyster beds and cultivated oyster lays. Larger vessels fish further offshore utilising demersal trawls and in recent years Dutch pulse beamers have fished offshore grounds (Mackinson et al. 2006; Thanet Fishermen's Association pers. comm. 2011, 2013).

The study region provides spawning areas for herring (autumn), lemon sole (spring and summer), sole (spring), and nursery areas for mackerel, herring, whiting, plaice and lemon sole (Coull et al. 1998; Ellis et al. 2012).

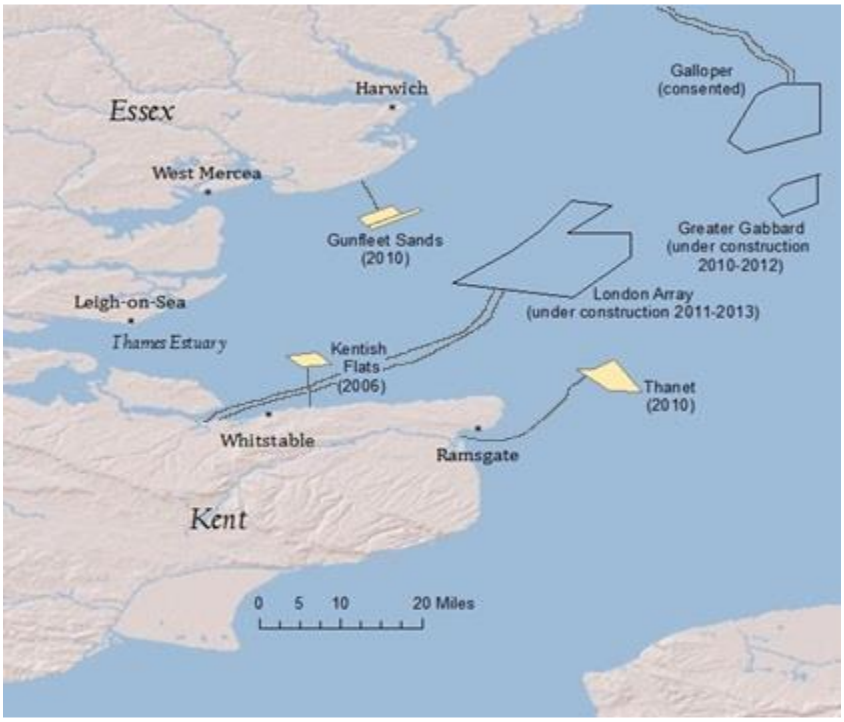


Figure 5.3 The Greater Thames study site, including cable routes at the time of the study, years in brackets refer to construction date.

Table 5.1: Over 10 metre and under 10 metre commercial fishing vessels registered with home ports in case study areas, (VMS was only available from vessels over 15m but MMO only distinguish between over and under 10m) (MMO vessel lists June 2011).

	2002		2011	
Case study region	Under 10 m vessels	Over 10 m vessles	Under 10 m vessels	Over 10 m vessles
Liverpool Bay	131	28	78	10
Greater Wash	137	77	70	66
Greater Thames	148	32	89	25

5.3 Methods

To provide the most complete assessment of changes in activity before and after OWF construction 3 separate data sets were identified, collated and analysed for each case study region (Fig 5.4). Two data sets, aerial surveillance and vessel monitoring system (VMS) data, were collated from existing fisheries enforcement records (surveillance data). VMS provides the most detailed source of fishing activity data but vessel positions are only returned every two hours, limiting detailed assessment of actual activity (Lambert et al. 2012). VMS equipment is only installed on vessels over 15 metres. These size vessels typically operate further offshore, beyond the inshore round one OWF case study sites. Aerial surveillance data covers all fishing activity but coverage is dependent upon the survey effort. In regions where survey effort (frequency of flights) is low the data must be interpreted with limited confidence (Vanstead and Silva 2010). The third data set adapts methods developed to map fishing grounds through face to face interviews with resource users (Wilen and Abbot 2006; des Clers 2010). Interview mapping was used to map activity before and after OWF construction in each case study region. This third data collection method provided direct resource user account of principal fishing grounds for both over and under 15m vessels. This method provided detailed information for the under 15m fleet in particular. These local inshore fleets are otherwise under represented in existing surveillance data.

Although a national programme was underway, using direct resource user interviews to map existing fishing grounds for the under 15m fleet for regional MCZ projects, data were unavailable due to confidentiality agreements (des Clers 2010; Lieberknecht et al. 2011; Regional Marine Conservation Zone Projects 2012). These data sets would also have only presented current activity in 2009-2010 and not examined changes from pre-OWF development years. The MCZ project fishing activity maps do present a useful reference source to compare activity data mapped in this study.

A geographical information system (GIS) template was designed in ARC GIS 10 to map spatial activity from each of the three data sets. Annual fishing effort within three distance categories from the first operational OWF was then calculated in each case study region, for both mobile and static fishing practices (gears) within the GIS (Fig 5.5a, 5.5b). Due to the different data collection methods for the three data sets each data set (VMS, aerial surveillance and interview mapping) were analysed separately.

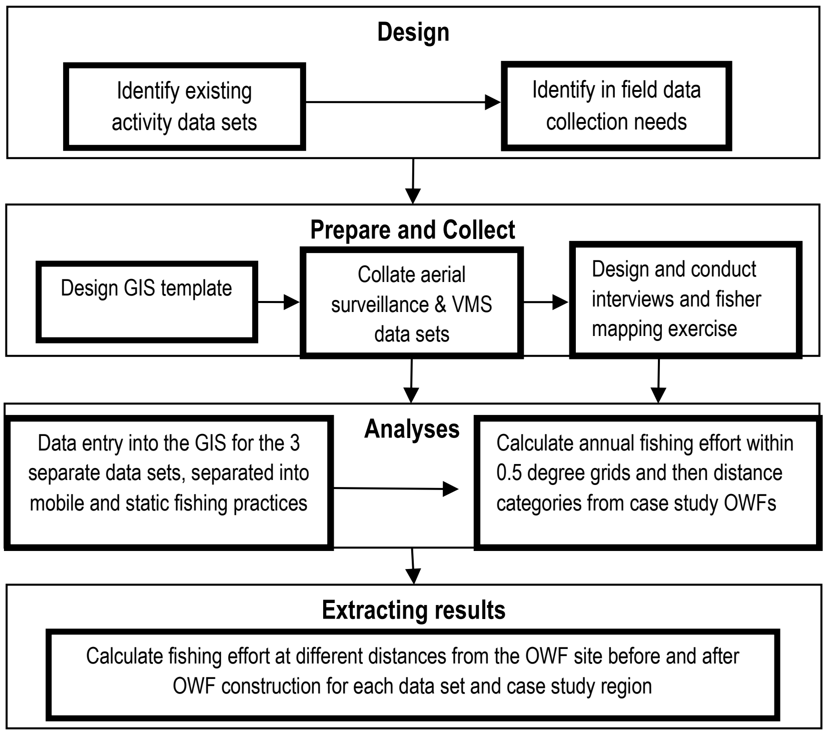


Figure 5.4. Systematic of data identification, collation and analyses procedure for assessment of changes in spatial fishing effort before and after OWF construction in each case study region.

5.3.1 Mapping fishing effort in ARC GIS 10

The GIS template utilised a 0.05 degree grid cell structure to allocate fishing effort from original point (aerial surveillance), grid (VMS data sets) and grid and polygon (interview mapping) data sets. Annual data sets for up to five years before and five years after initial OWF construction in each study area were utilised where possible from aerial surveillance and VMS data. Interview mapping provided a representation of effort distribution within a typical year before construction and a typical year after. Data were extracted for three spatial scales in relation to the OWF which had been operating the longest in each study region (Fig 5.5). The first category was effort near to the OWF which extended from the centre of the OWF to within 2 kilometres of the site boundary. The second category (mid), provided effort data within a zone that extended from 2km from the OWF site boundary to within 10 kilometres of the OWF site. The third category (far) included effort from the 10 kilometres boundary to within 20 kilometres of the OWF boundary. Fishing effort displayed within the wider grid beyond 20 kilometres was observed and although not included in the analysis provided information for discussion and interpretation of results.

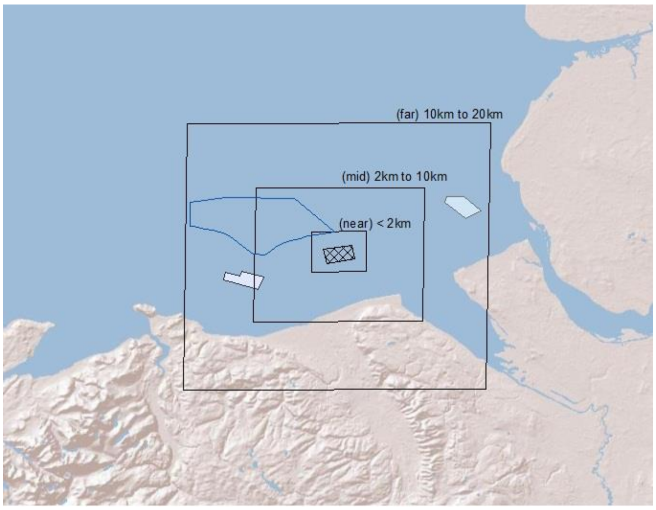


Figure 5.5a. Distance categories designed as quadrats (solid lines labelled near, mid and far) which were used in the analysis of fishing activity for each data set, recording activity in each year before and after construction. North Hoyle OWF is contained within the black box with hashes, Burbo Bank and Rhyl flats are the solid light shaded shapes, Gwynt Y Mor is the hollow shape.

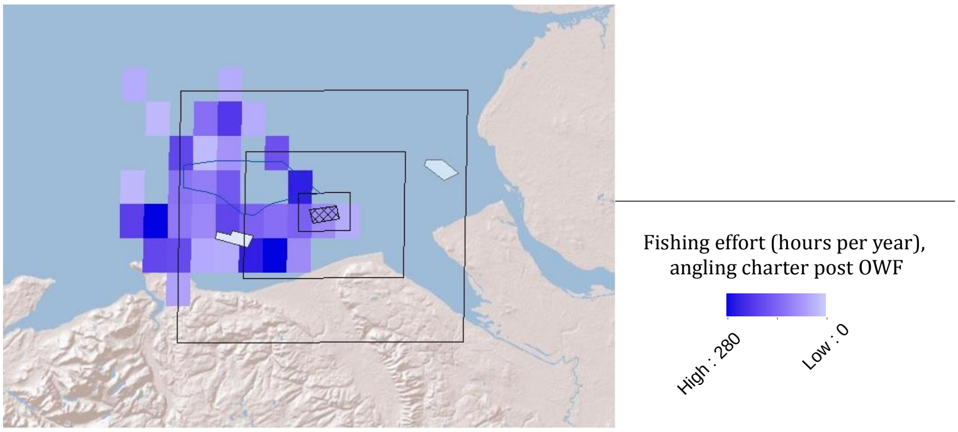


Fig 5.5b Example of the GIS layer produced to calculate fishing activity at different distance categories from North Hoyle OWF; in this example each cell contains combined data from all interviews.

Results were initially combined across the three study sites for each gear type and distance category to give a national perspective, and identify trends that persisted across regions. Subsequently the individual case study sites were analysed separately to investigate regional and site specific trends.

5.3.2 Data extraction and analysis methods – individual activity data sets

Three separate data resources were utilised to provide as comprehensive representation of fishing effort by vessels of different length classes as possible. Satellite vessel monitoring system data (available only for vessels over 15 metres), aerial surveillance covering all vessel sizes and face to face mapping of grounds (carried out during fishermen interviews for locally based vessels) were analysed independently but using the spatial methodology detailed above.

5.3.3 Interview based fishing activity maps

In the interview fishermen were asked to provide details on vessel size, engine power, length of average trips and frequency of trips as well as gear types used and species targeted through the year (Appendix 2). Fishermen were then requested to map fishing activity (gear type, species targeted and days fished in that location) on two copies of the same admiralty chart of the area. The first chart mapped information on current activities through the year, the second mapped information on seasonal activities prior to OWF construction in the region. For reference the chart had the 0.05 degree grid overlaid matching the cells used in the geographic information system (GIS) analyses. Respondents were asked to circle the fishing grounds used in relation to the information given in previous questions on season, gear type, length of trip, target species and percentage contribution to annual fishing effort (Appendix 2).

The 0.05 degree grid was used to match the spatial resolution utilised in the methodology developed by Vanstead and Silva (2010) for mapping of fishing activity data from UK inshore fisheries and conservation authorities and UK aerial surveillance data sets (Eastwood 2005, Vanstead and Silva 2010). This grid design provided grid cells at 1/400th of an ICES rectangle which matched the resolution of data sets provided by the UK MMO for aggregated VMS records.

5.3.4 Mapping fishing effort values from interview data

The information provided by the mapping exercise and relevant question answers were then interpreted as spatial fishing effort (Figure 5.5 b). To create a data set representing yearly activity the percentage of annual activity spent on each fishing practice that was mapped by an individual fishermen was interpreted as number of days out of a total of 100 days fishing annually. Hours fishing on daily trips were then multiplied by the number given as a percentage of annual activity for each fishing practice. These approximated values for time fishing in hours were divided between the grounds identified by each individual fisherman for that fishing practice.

This information was interpreted to map fishing effort for each fisherman in a typical year prior to OWF construction and a typical year post OWF construction as a distribution of time (hours) spent fishing each ground identified the study region. Time in hours is therefore not an exact time in hours spent fishing over a 365 day year but out of a representative 100 days fishing over the course of a year (each season providing 25 days). This activity was mapped in ARC GIS 10 for each fishermen interview as shape files utilising either point data or polygon data across the area marked or circled by the fisherman. Separate shape files were created for each gear type and season category. These shape files were then converted to a raster data set for effort (hours) for each gear type and season category with the cell size set to the 0.05 degree grid utilised across data sets.

Each interview was treated as an individual sample following the methods provided by Daw (2008a). The total fishing effort provided by each fisherman within each distance category was divided by the number of grid cells contained within each distance category. This provided a mean value of fishing effort within each distance for each fisherman. If any area from a coloured cell lies within a distance category, data from that cell is included in that category. This resulted in some values being duplicated between categories but allows for the likelihood that activities such as trawling, laying a string of pots or drifting while angling may cross the borders of quadrats.

This process was repeated for both before and after maps to provide data sets for fishermen operating mobile and fishermen operating static gears. Data were compared using bar chart plots. To statistically test differences between spatial distribution of fishing effort before and after OWF construction the data were tested for normality of distribution with the Shapiro-Wilk test and homogeneity of variance with Levene's test (IBM SPSS). As each fisherman interview provided a paired sample for periods before and after construction for each distance category paired t-tests were used to provide statistical tests of differences. A Bonferroni correction was applied to account for the possible number of tests according to sample number in each case study region.

5.3.5 MMO aerial surveillance data

Aerial surveillance data were provided by MMO in spreadsheet format containing individual vessel sightings for flights conducted between 1998 and 2011. Data sets were requested for the ICES rectangles incorporating the OWF developments in each study region and the surrounding sea space. These were rectangles 35E6 and 36E6 for Liverpool Bay, rectangles 34F1, 34FO, 35F1, 35FO for the Greater Wash region and rectangles 31FO, 31F1, 32FO, 32F1 for the Greater Thames region. Date of sighting, ICES rectangle and sub-square, vessel location in latitude and longitude, country of registration, vessel/gear type and activity (fishing, laid stationary or steaming) were present in the original data set.

Sightings were separated by year and by gear type (mobile and static). To account for survey effort in the absence of confidential flight path information from the UK Navy and Air Force survey effort was calculated using dates to identify individual flight surveys. The method applied by Eastwood (2005) and Vanstead and Silva (2010) to calculate sightings per unit effort (SPUE) was adapted to suit the data available (SPUE = number of sightings within distance category / annual surveillance effort).

Sightings occurring within the ICES rectangles on the same day were considered to be recorded within the same survey. The total number of surveys for each year was calculated as the total number of individual days in each annual spreadsheet. Each sighting in a year was divided by the total number of surveys calculated for that year to provide a value of sightings per survey effort.

To map sightings within the GIS each sighting within each gear type was assigned the SPUE value for that year. Using the latitude and longitude data within the spread sheet all sightings for each gear type and for each year were plotted in ARC GIS 10 using the ‘add x y’ data function to create a point file. Separate point files were created for mobile and static gears.

To calculate total sightings per survey effort values (contained within the point data in each point file) for each gear type in each year within 0.05 degree cells the point to raster tool was used. The total point data SPUE values were calculated for the 0.05 grid cell that encompassed the location of those points.

To calculate annual sighted fishing effort within distance categories from the OWF site, SPUE was totalled within each distance category for mobile static activity data sets in each year (near; < 2km from the site, mid; 2km to 10km from the site and far; 10km to 20km from the site).

Total SPUE values for static and mobile gears within each distance category were plotted across time (years) before and after OWF construction. Statistical comparison of SPUE of mobile and static gears for the five year period before construction and the five year period after construction (3 years for Greater Wash due to later construction dates) was undertaken for each distance category. Years were grouped as before and after construction and Levene's test for equality of variance and Shapiro-Wilk test for normality of distribution were undertaken (IBM SPSS) within these groups. T tests for unequal variance (Welch's test) were calculated to account for unequal variances present in the data.

5.3.6 VMS data

VMS data were supplied by MMO for the whole of the UK including the Liverpool Bay study site aggregated for grids at the 0.05 degree, (1/400th ICES rectangle) spatial scale. Fishing activity was aggregated by gear type on an annual basis within each grid cell. This provided annual data sets with total time spent fishing (minutes) for all vessels, total catch wet weight and total value of catch for each grid cell and further data sets with data split for mobile and static gears. Data could only be supplied for the years 2007, 2008, 2009 and 2010 out of the requested data sets for 2000 to 2010 as raw VMS and log book data had only been aggregated for these years and commercial sensitivity of data prevented raw data or lower levels of aggregation being supplied by MMO.

Whilst the available data provided only after OWF construction analysis of fishing activity at North Hoyle, Liverpool Bay and Kentish Flats, Greater Thames, the data were included to provide a methodology to combine mapping data, aerial surveillance and VMS within regions. The VMS data set did provide 2 years pre and 1 years post-construction data for Lynn and Inner Dowsing OWFs. This not only provided the most detailed data sets possible with available data in each region, improving confidence in overall results but provided independent data sets that could be used to verify the patterns observed between different survey methods.

VMS data were already in the 1/400th ICES rectangle spatial scale with data contained in a format (GIS layer) that could be integrated into a GIS without prior processing. Each annual VMS data set was opened in the ARC GIS 10. To analyse fishing effort and activity over time, the value for time spent for each gear type in each cell within distance categories near, mid and far (under 2km, 2 to 10 km and 10 to 20km) was extracted from each annual data set.

Mean time spent in each year was calculated by dividing the total time for each gear type by the number of cells within each distance category. These data were plotted in line charts. Shapiro Wilk and Levene's tests were used to test for normality of distribution and variance. Welch's t tests were used due to the unequal variance present in the data to compare fishing activity between before and after construction year groups within each distance category in the Greater Wash region.

5.3.7 Landings data

Wet weight landings data were provided by MMO for the ICES rectangle containing the first operational OWF in each study region. Data were separated into species groups, mixed demersal fish (typically targeted by mobile trawls), shellfish and scallops. Flatfish and elasmobranches were separated for analysis due to the possible effects on distribution identified in earlier chapters. Total wet weight was calculated for each species category for each year. Annual wet weight totals for each species group were separated into before and after the year of OWF construction. Levene's test for equality of variance and Shapiro-Wilk test for normality of distribution were undertaken (IBM SPSS) within these groups. As unequal variances were present in the data *t*-tests for unequal variance (Welch's test) were calculated (Ruxton, 2006). Further options considered were student's *t*-tests if variance equal and distribution within normality. Transformations of data could also have been undertaken to reduce inequality of variance present in the data. Non-parametric tests could also have been undertaken to provide tests on data with unequal variance.

Data confidentiality issues prevented MMO providing individual vessel IDs in relation to landings, sightings or VMS data which would have provided a means of linking landings to catch locations (all be it with restricted resolution) (Gerritsen and Lordan 2011). The landings data can therefore only provide very broad-scale information, that can only identify the greatest impacts from OWF development, changes in fishing policy, environmental effects and other factors influencing regional fisheries.

5.4 Results

5.4.1 UK wide

i) Mobile gear fishing activity.

All fishermen approached provided mapping and interview responses. Fishing effort for mobile vessels reduced in close proximity to OWFs post-construction but remained similar at greater distances from OWF sites (Fig 5.6 a, b, c). Combined results from all UK development regions did not indicate increased fishing activity or landings in relation to OWF developments. However the number of fishing vessels registered across the three case study regions declined by 39% between 2002 and 2011 reflecting the decline of 16% across the whole UK according to MMO statistics (Table 5.1) (MMO 2013a). The decrease in activity in proximity to OWFs, and increase in activity at mid and far distances from OWFs, indicated displacement of effort has been a more likely effect than exploitation of grounds adjacent to OWFs by mobile gear fisheries (Figure 5.6 a, b, c). Monitoring data for before and after effects was limited to aerial surveillance, which is not intended for investigating small scale temporal changes in activity. Therefore, the general decrease in fishing activity in proximity to developments may also be due to other policy, management or ecological issues.

ii) Static gear fishing activity

Static fishing activity showed an increase at mid and far distances in all data sets except VMS data (Fig 5.7 a, b, c). Increased activity from static fishing gears within 2km of OWFs was also displayed in aerial surveillance data sets for two sites (Fig 5.7,a, Table 5.2). Aerial data had relatively low survey effort so these peaks, even when data is combined may be due to relatively small levels of activity and should be interpreted with caution.

ii) Landings (wet weight)

Combining wet weight landings of demersal fish from the three case study regions displayed a decline in flatfish landings after 2002 when OWF construction began, from 108 tonnes in 2002 to 17 tonnes in 2011. Landings of other demersal fish species were more consistent but there were occasional large peaks in 2002 and 2003, as well as 2008, 2009 and 2011 (Fig 5.8). A steep decline was seen for crustacean landings in combined data from OWF development regions between 2002 and 2005, reducing from 1339 tonnes in 2002 to 216 tonnes in 2005, with landings remaining steadier between 2005 and 2011 (Fig 5.8).

All areas combined:

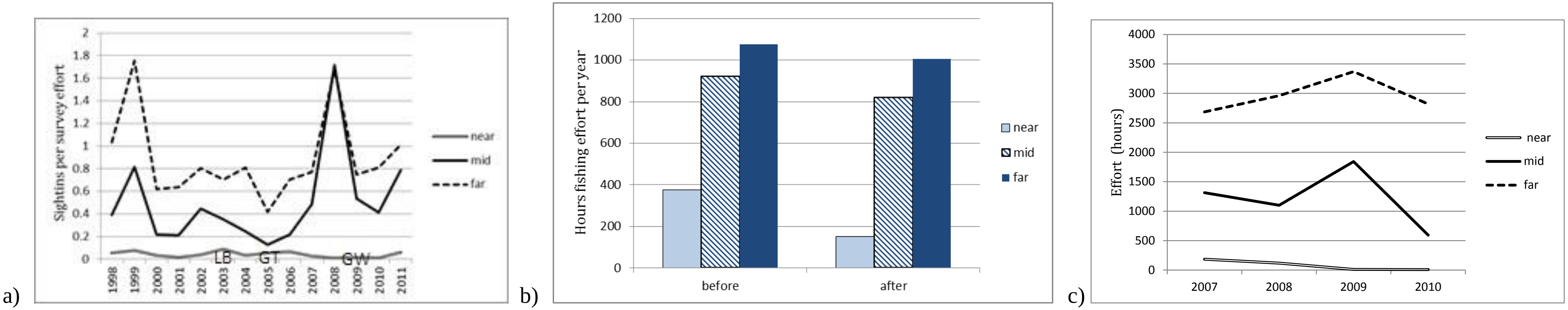


Figure 5.6 Mobile gear fishing activity: a) aerial, (Letters refer to year of first operating OWF in each study region, Liverpool Bay (LB), Greater Thames (GT) and Greater Wash (GW)) b) interview, c) VMS.

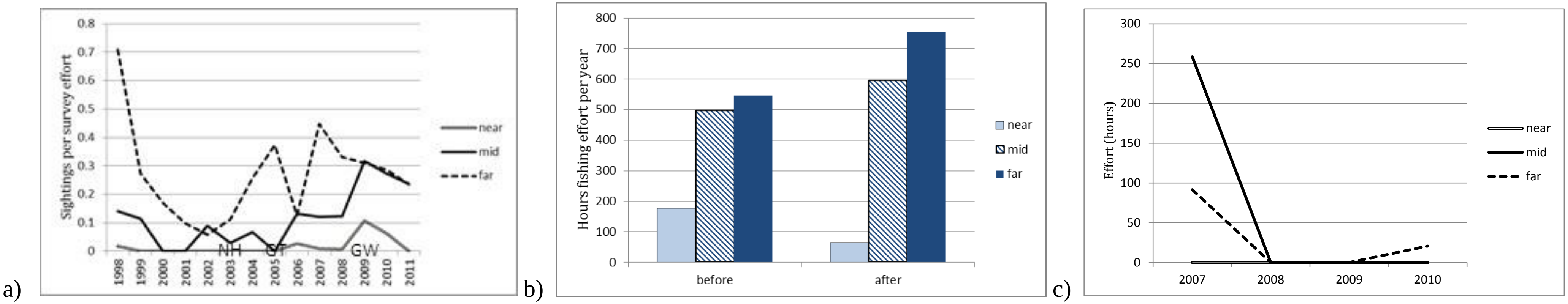


Fig 5.7 Static gear fishing activity: a) aerial, (Letters refer to year of first operating OWF in each study region, Liverpool Bay (LB), Greater Thames (GT) and Greater Wash (GW)) b) interview, c) VMS.

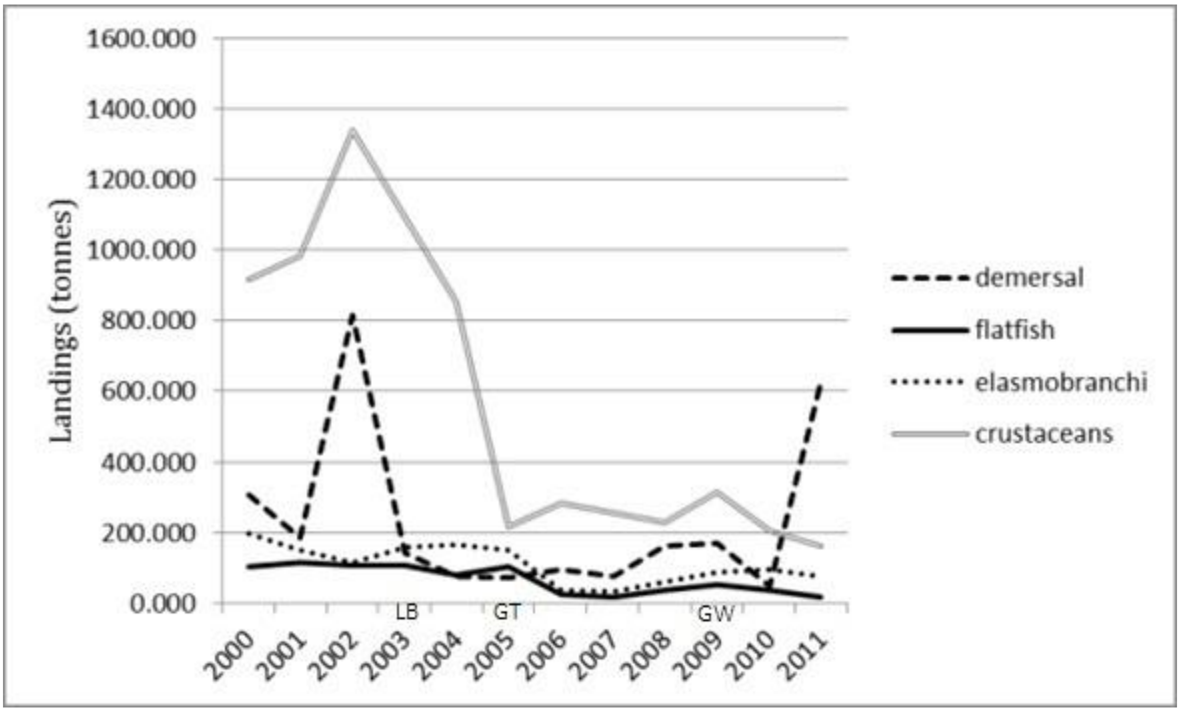


Figure 5.8. Landings (wet weight, tonnes) all case study regions, (Letters refer to year of first operating OWF in each study region, Liverpool Bay (LB), Greater Thames (GT) and Greater Wash (GW)).

5.4.2 Fishing effort distribution and landings within study regions

i) Effort distribution

Mobile gear fishing activity

Fishing effort (activity) and landings comparisons for data 5 years pre and post-construction in Liverpool Bay and the Greater Thames regions, and 3 years pre and post-construction in the Greater Wash revealed region specific differences. No region displayed significant mobile fishing effort targeted within close proximity to OWFs. Mobile fishing activity decreased in close proximity to North Hoyle OWF in Liverpool Bay, and Lynn and Inner Dowsing OWFs in the Greater Wash study areas. Mobile fishing activity remained similar pre and post-construction in proximity to Kentish Flats OWF in the Thames Estuary from aerial surveillance data, although interview mapping suggested decreased activity (Table 5.2, 5.3). Reduction in mobile fishing effort near to an OWF was only significant for interview derived mapping data in Liverpool Bay (Welch's t test p= 0.05) and for aerial surveillance derived mobile fishing activity in the near distance category to Lynn and Inner Dowsing OWF, Greater Wash (Welch's t test p = 0.03) (Table 5.2 a).

Table 5.2. Fishing effort changes within each study region at different distance categories from the first operational OWF after OWF construction a) near, b) mid and c) far distance categories. Increased activity (↑), no change (< >) , decreased activity (↓) statistically significant changes are indicated by *, blank cells indicate no data were available. Reading from left to right the first result is VMS data, then aerial surveillance data then interview mapping data.

		Liverpool Bay			Greater Wash			Greater Thames		
		VMS	Aerial	Interview	VMS	Aerial	Interview	VMS	Aerial	Interview
NEAR (a)	Mobile		↓	↓*	↓*	↓	↓		↔	↓
	Static		↓	↓		↑	↓		↑*	
MID (b)	Mobile		↓	↓*	↓	↓	↑		↑*	↓
	Static		↓	↓		↑*	↑		↑*	
FAR (c)	Mobile		↓	↓	↑	↔	↑		↑*	↓
	Static		↑	↔		↓	↑		↑*	

Table 5.3 (a,b,c,) Data associated with Table 5.2, VMS (total hours before and after in each distance category), Aerial surveillance (SPUE in each distance category), Interviews (total hours before/after).

Liverpool Bay		VMS (hours)		Aerial (SPUE)		Interview (hours)	
		Before	After	Before	After	Before	After
Near	mobile		0	0.017	0	62	6
	static		0	0.033	0.016	80	50
Mid	mobile		909.1	0.052	0.038	102	12
	static		0	0.158	0.128	72.4	63.9
Far	mobile		588.9	0.121	0.117	191	72.5
	static		28.1	0.364	0.42	66.2	62.5

Gt. Wash		VMS (hours)		Aerial (SPUE)		Interview (hours)	
		Before	After	Before	After	Before	After
Near	mobile	183.75	10.933	0.018	0	206.6	112.5
	static	0	0	0.003	0.051	72	24
Mid	mobile	1012.61	880.89	0.261	0.126	448.9	490.6
	static	0	0	0.034	0.144	264	402
Far	mobile	1342.02	2593.4	0.22	0.227	490.8	592.1
	static	0	0	0.116	0.068	363	579

Gt. Thames		VMS (hours)		Aerial (SPUE)		Interview (hours)	
		Before	After	Before	After	Before	After
Near	mobile		0	0.025	0.028	107.5	32
	static		0	0	0.005		
Mid	mobile		8.31	0.11	0.184	371.3	317.5
	static		0	0.025	0.19		
Far	mobile		108.15	0.116	0.215	392.5	342
	static		0	0.107	0.19		

The trend for decreased effort from mobile fishing practices continued post-construction at mid distance categories from operating OWF in Liverpool Bay and the Greater Wash (Table 5.2 b). In the Greater Thames mobile effort displayed the opposite trend, increasing significantly at this mid distance category (Welch's t test p = 0.04, as well as the far distance category (Welch's t test p = 0.05) (Table 5.2 b, c,). As sightings from aerial surveillance data are rare, a small number of vessel sightings are responsible for a significant result in this region (Table 5.4).

Weaknesses in the data resources available for vessels under 15m must be considered. Aerial surveillance is not designed for surveying change in fishing activity on a fine scale and interviews may be influenced by incentives, such as financial compensation for lost fishing grounds. Other policy and management actions and environmental changes may also influence fishing activity. These other issues were approached directly in interviews conducted during the mapping exercise, and are discussed in the following chapter. On-board vessel monitoring systems provide the most accurate activity information but, at the time of this study were only available for vessels over 15m, with data from 2007 onwards.

VMS data were only available for before and after (round one) OWF construction comparison in the Greater Wash. In Liverpool Bay and the Greater Thames these data sets did, however provide information on the activity of vessels over 15m in these regions whilst OWFs were operating. VMS results for mobile vessels in the Greater Wash displayed decreasing effort in the near and mid distance categories from operating OWFs. Decreases in time (hours fishing) in the near distance category were statistically significant (Table 5.2 c, Table 5.3). VMS results support the patterns seen in aerial surveillance and interview activity data sets in the Greater Wash study region.

Aerial surveillance records between 1998 and 2011 contained decreased frequency of sightings (per survey effort) of large highly mobile beam trawlers in the wider Liverpool Bay/Eastern Irish Sea area. In the wider Eastern Irish Sea region there was an increase in scalloping vessels offshore. Short periods of intense scallop dredging activity led to high effort values for mobile fishing activity in mid and far distance categories from VMS data in Liverpool Bay. In the Greater Wash region a similar decline is seen at all distance categories in aerial surveillance and VMS data records for mobile vessels (Table 5.2 a, b, c). Direct benefit to mobile gear fisheries from fishing in close proximity to OWFs are not suggested by patterns in these regions.

Mapping of interview data from mobile gear fishermen who were active in 2011 suggests fishing effort had decreased within 2km of OWF sites post-construction (Table 5.2 a). Fishermen interviewed were utilising otter trawling for plaice and sole in Liverpool Bay, beam trawling for pink and brown shrimp in The Greater Wash and otter trawling and drift netting for sole and mixed demersal fish in the Greater Thames. Results indicating an increase in fishing activity over time in a study area are only present in the Greater Thames region. Increases in effort are indicated over time by aerial surveillance at distance categories further from the OWF and similar levels of activity pre and post-construction, in proximity to Kentish Flats OWF (Table 5.2 a, b, c). VMS data were not available pre-construction for Kentish Flats OWF. Also a very low sample size for interviews limited confidence in before after comparisons using interview data sets for the Greater Thames region.

Changes in numbers of registered vessels in each study region, as well as policy, management and environmental issues affecting fisheries in each region may also explain the different characteristics in fishing effort seen over time. For instance: vessels (over and under 10m combined) registered with home ports within Liverpool Bay decreased by 45% between 2002 and 2011 compared to smaller decreases of 36% and 37% in Greater Thames and Greater Wash respectively (Table 5.1).

Static gear fishing activity

Analysis of static fishing activity primarily relied on aerial surveillance and interview mapping data sets, as vessels were typically under 15m and did not carry VMS equipment. Across all three regions static activity covered fishing with pots or traps (for lobster, crab and whelks), static gill nets, long lines and rod and line angling. Results showed increased effort near to operating OWF in the Greater Wash, and a significant increase in the Greater Thames (aerial surveillance, Welch's t test $p = 0.04$) (Table 5.2 a). The same pattern occurred in these two regions at mid distance categories, with the increase in the Greater Thames again significant (Greater Thames, mid distance increase Welch's *t* test $p = 0.03$) (Table 5.2b). It is important to consider again that these increases appear in aerial surveillance data only, which returns few sightings from limited survey effort, reducing confidence in the results (Table 5.4). Only static activity in Liverpool Bay, analysed from interview mapping data (primarily from rod and line angling charter operators), displayed decreased effort near to an existing OWF (North Hoyle) and significantly decreased activity at the mid distance category (Welch's *t* test $p = 0.019$). Static fishing activity in Liverpool Bay displayed increased activity (not significant) at the furthest distances, suggesting displacement of effort (Table 5.2 a, b, c). A small regional crab and lobster fishery also added to increases for static fishing activity in the far distance category in the Liverpool Bay region.

Table 5.4. Number of surveillance flights annually in each region from 1998-2011 (data supplied by MMO, 2012)

Year	Number of flights per year		
	Liverpool Bay	**Greater Thames**	**Greater Wash**
1998	53	129	69
1999	50	116	48
2000	61	116	43
2001	54	105	38
2002	51	105	37
2003	47	96	39
2004	30	92	29
2005	36	71	18
2006	36	107	36
2007	24	113	52
2008	26	174	42
2009	26	189	31
2010	17	190	52
2011	61	158	20

Overall there was very little activity from over 15m vessels operating static gear fishing methods in the inshore area near to OWFs (Fig 5.7c). Only mobile fishing vessels over 15m were consistently active in these distance categories with no VMS data for static gears (Table 5.2 a, b). The lack of VMS records for static activity in these distance categories suggests that increased static gear activity appearing in proximity to OWFs in The Greater Wash and Greater Thames was due to smaller under 15m vessels.

Landings

Table 5.5. Changes in landings following construction of the first operational OWF in each study region, increase (↑), no change (< >), or decrease (↓), * indicates statistically significant changes.

	Liverpool Bay	**Greater Wash**	**Greater Thames**
Demersal	↓	↓	↓*
Shellfish	↓	↓	↓
Flatfish	↓	↓	↓*
Elasmobranchi	↓	↓	↓*

Table 5.6. Wet weight landings (tonnes) for each of the species groups in each study region (ICES rectangle containing the first operating OWF in each region a) Liverpool Bay, b) Greater Wash, c) Greater Thames.

a) Liverpool Bay

	Liverpool Bay			
	Demersal	Flatfish	Sharks, Rays	Crab, lobster
Before (t)	169.6	27.5	36.3	110
After (t)	73.6	17.7	14	49.2

b) The Greater Wash study region

	Greater Wash			
	Demersal	Flatfish	Sharks, Rays	Crab, lobster
Before (t)	14.4	3.3	5.5	609.5
After (t)	13.2	2.2	5	159.3

c) The Greater Thames study region

	Greater Thames			
	Demersal	Flatfish	Sharks, Rays	Crab, lobster
Before (t)	176.6	78	120.4	52.3
After (t)	74.5	7.6	51.3	33.7

Specific species benefits were not discernible from landings data. Other factors such as quotas, vessel activity and broad scale natural variation in species abundance, within the large area covered by the data resolution (ICES rectangle 4000 square kilometres) must be considered when interpreting landings information. Despite increased effort from static gear fisheries in two of the three study sites, landings (wet weight) of crustaceans were lower post-construction across the ICES rectangles containing operating OWFs in each study area (Table 5.2 a, b, c, Table 5.4, Table 5.5 a, b, c).

Decreased landings of demersal fish and specific species groups of interest, flatfish (Pleuronectidea) and sharks and rays (Elasmobranchii) were also seen in each of the study sites (Table 5.4, Table 5.5 a, b, c). Decreases for Crustacea, as well as Pleuronectidea and

Elasmobranchii were significant in the Greater Thames (Welch's t test, p = 0.04, p= 0.01, p= 0.01, respectively). These decreases occurred despite increased activity from towed gear and drift net fisheries within both mid (10km) and far (20km) distance categories from Kentish Flats OWF (Table 5.2 b, c Table 5.5). Liverpool Bay displayed large declines in landings of all species groups though no decline was statistically significant (Table 5.5, 5.6). The Greater Wash displayed the smallest declines in demersal fish, flatfish and shark and ray landings although landings were very small in this region before OWF construction. The significant regional crab and lobster potting fishery however did display a significant decline in landings in the Greater Wash region (Welch's t test p= 0.016) (Table 5.5, 5.6).

5.4.3 Summary of Results

The operating OWFs across study areas limited accessibility to a total of 131 km² of sea bed and provided approximately 38480 m² of new hard substratum within the water column (Wilson and Elliott 2009). Each data set had identifiable weaknesses for accurately identifying actual small scale changes in fishing activity (Wilen and Abbott 2006; Vanstead and Silva 2010; des Clers 2010; Lambert et al. 2012). Despite limitations in data sets, a trend for decreased fishing activity near to OWFs was identified for mobile fishing activities. At far locations from OWFs, a similar trend for decreased mobile fishing effort was seen in two of three study locations, suggesting wider factors and a general decease in active vessels may attribute to decreased activity near OWF sites, as well as OWF development. Static fishing activity displayed either a smaller decrease, (Liverpool Bay) or small increases in activity, near to operating OWFs (Greater Wash and Greater Thames, aerial surveillance data). This also represented a general trend at far distances in two case study sites, suggesting other social or environmental factors may influence these trends.

There were no noticeable benefits to catches from OWFs, at the scale of the regional ICES rectangles encompassing the case study sites. Decreased landings occurred for the species identified throughout the earlier chapters as being positively affected (crab, lobster and gadoid fish such as cod and whiting). Decreased landing also occurred for those species identified as showing no affect or being negatively affected by deployment of OWFs and other artificial structures (flatfish species, sharks and rays). Without vessel identification (due to commercial sensitivity requirements) landings cannot be attributed to catch locations, therefore, limiting the ability to relate changes in catches and landings to OWF development.

Activity data sets for vessels under 15m were limited to surveillance designed for enforcement and management purposes. These data sets were not designed for ascertaining change in fine scale distribution (aerial surveillance data). Recognised limitations in interview data were that results represented local fleets but not fishermen from other regions. Interview responses could also potentially biased by financial incentives, such as compensation as part of mitigation agreements. However, trends present in VMS data in the Greater Wash were represented in interview data, suggesting responses were accurately representing changes in fishing effort. The interview methods also provided a means to interpret fishing activity changes in relation to policy, management and environmental issues which are discussed in Chapter 6.

5.5 Discussion

This chapter aimed to identify if patterns of effort displacement or increased fishing opportunities close to OWF sites are occurring for either static or mobile gear fisheries. The fishing activity and landings data were also utilised to investigate if species benefits or disadvantages, identified in earlier chapters, were recognisable in patterns of fishing effort and landings records for pre and post-construction periods in three case study areas.

5.5.2 Results in relation to national trends

Declining wet weight landings for the key fish species of interest in this study can be identified to have also occurred nationally. Combined wet weight landings of demersal fish from the three case study regions revealed similar trends to national statistics for landings of cod and plaice (MMO 2013a). Data sets in this study and in national statistics displayed a slight decline in flatfish landings and consistent landings of demersal fish after 2002, when OWF construction began (MMO 2013a). The steep decline seen for crustacean landings in development areas between 2002 and 2005, followed by landings remaining steadier between 2005 and 2011 was opposed to the national trend. Nationally Nephrops landings increased and landings of crab remained consistent during this period (MMO 2013a).

Nationally the number of fishing vessels registered in the UK declined by 16% between 2002 and 2011 whilst the combined reduction of registered vessels in OWF development regions was far greater at 39% (MMO 2013a). Despite reductions in the number of active vessels, fishing continued in all case study regions although activity decreased in two of the three case study sites. Displacement of effort was evidently a more likely effect than exploitation of grounds adjacent to OWFs by mobile gear fisheries. The reduction in wet weight landings in these regions in comparison to national trends may reflect both an effect of construction activity as well as the greater reduction in active vessels compared to national statistics. Without access to vessel identifiers and log book data (unavailable due to commercial sensitivity restrictions at the time of the study), landings could not be attributed to catch locations to separate effects of development from broad scale trends (Gerrtisen and Lordan 2011).

Static fishing effort did show increased activity at each distance category, including within 2km of OWFs in aerial surveillance data sets. This may reflect a national trend for increased effort, leading to the increased landings of crab and Nephrops in UK wide statistics, or suggest benefit to catches near to OWF that are unidentifiable from landings data at the ICES rectangle scale.

5.5.3 Regional changes in activity and landings

Effort from mobile fishing practices was either increased in offshore grounds or activity reduced considerably post-construction in two case study sites, Liverpool Bay and the Greater Wash. Within the third site, the Greater Thames, fishing activity showed an increase at all distances from the OWF site. In the Wash, fishing activity and effort distribution appeared to reflect the reduction in active registered fishing vessels and national trends in landings, with deceased mobile fishing activity and increased static fishing activity across the region.

In the Greater Thames region the aerial surveillance data sets provided the most consistent data source and displayed increased static and mobile activity, going against trends in numbers of active vessels and national trends for demersal species landings (MMO 2013a). The increased landings of shellfish species in national statistics, possibly reflecting increased effort, are reflected in the increased static gear fishing effort in at all distances from the OWF (MMO 2013a). It is also possible that increased effort in the Greater Thames study region is related to increased survey effort from aerial surveillance activities (Vanstead and Silva 2010). The aerial surveillance effort almost doubled in the Thames region post-construction (Table 5.3). Sightings from aerial surveillance close to inshore OWFs are infrequent in all data sets. Therefore, individual sightings across a year significantly increase SPUE values and differences between before and after construction comparisons (Vanstead and Silva 2010).

Confidence in results is limited by the level of data available for research projects (due to commercial sensitivity restrictions and limited spatial monitoring of activity of vessels under 15m). The results suggest that existing OWF developments are putting spatial pressure on fishing activities, as a trend of deceased fishing effort is seen near sites. Results also suggest that limited opportunities for fishing within proximity to OWFs have been created as significant increases in effort were not seen. The opposite trend is seen at European artificial reef sites that are designed specifically to replicate natural habitats. Catches from near to artificial reef sites provided income above national minimum wages (Ramos et al. 2006).

The patterns in changes of fishing effort distribution in OWF development regions reflect fishermen's perceptions recorded during the early stages of OWF development (Mackinson et al. 2006). Mobile fishing activity displayed no identifiable increase in fishing activity near, or within operating OWFs with effort decreasing post-construction. Displacement of mobile fishing activity from grounds containing OWF developments is suggested by reduction in effort in near distance categories. As reductions are seen in VMS, aerial and interview data this trend appears likely to occur regardless of vessel size. Data sources were limited as landings could not be attributed to fishing locations and data resources were limited for vessels under 15m. The similarity to national trends suggests policy, management and environmental issues may also be influencing fisheries in development regions, these factors are explored further in Chapter 6.

Economic impact will be more significant for smaller inshore vessels with limited flexibility to adapt to loss of ground (Mangi et al. 2011). At the time of the study, larger round two sites were only present in the Thames region and no round three sites had begun construction (Figs 4.1 a, 5.2, 5.3). If similar patterns in activity changes for mobile and static gear fisheries continue at this greater scale, especially as the larger OWF developments occupy more important fishing grounds, mobile fishing activity will be increasingly displaced onto remaining grounds (Dinmore et al. 2003; Hutton et al. 2004; Mackinson et al. 2006; Greenstreet et al. 2009). Economic impacts and environmental effects will possibly become increasingly apparent if trends are extrapolated to the scale of the largest developments, in particular UK Round 3 leased areas on productive fishing grounds.

5.5.4 Ecological considerations

Consideration of effort displacement and the knock on effects of area closures is increasingly being called for when considering the overall ecological impacts of area closures on a wider region (Hutton et al. 2004; Hiddink et al. 2006; Greenstreet et al. 2009). OWF development is currently centred in Europe, where limited available marine space and a variety of large fishing fleets exist. The lack of fishing effort in proximity to OWFs may enhance their presence as *de facto* marine protected areas and aid certain fish stocks. However, the loss of available ground has already been identified as a significant impact on inshore and offshore fishing fleets (Mackinson et al. 2006). Prior to area closures fishers will have made decisions on spatial locations of operation on the basis of past catch rates (Hutton et al. 2004). Therefore, it can be assumed that in the case of an OWF development, boats successfully utilising that ground during particular seasons will be forced to search for new less familiar grounds. This will lead to greater fuel costs and less predictable catches during that period (Mackinson et al. 2006; Blythe Skyrme 2010, 2011).

Hiddink et al. (2006) modelled the effect of redistribution of beam trawl effort on benthic communities following assumed area closures in the North Sea, using this assumption that fishers select grounds based on their knowledge of past catches. The random utility model used predicted redistribution to impact biomass, production and species richness of benthic communities, with a trade-off between the negative impact on open areas and the recovery of closed areas. The findings of this study suggested that closure of lightly fished areas had the strongest positive effect. Closing large areas, especially those receiving high fishing effort concentrated that effort within smaller spatial scales, increasing the regional impact on benthic communities. Without reducing allowed fishing effort concurrently with area closures, positive effects of the area closure were identified to potentially be outweighed by negative impact of the redistributed effort (Hiddink et al. 2006).

At the state of development in 2011, OWFs occupied only lightly fished areas, representing the best case scenario for area closures in these regions (Hiddink et al. 2006). As development progresses with larger OWFs being constructed and encroaching on more important fishing grounds the ecological impacts will progressively increase in remaining grounds. OWF development regions typically contain extensive soft bottom habitats. Benthic communities within these habitats show slow recovery from fishing impacts, particularly epifauna species taking many years to recover (Kaiser et al. 2006). These complex epifauna communities and the complex substratum such as pebbles removed by mobile fishing practices provide important habitat for juvenile stages of many commercial fish species (Auster et al. 1996; Lindholm et al. 2001).

Greenstreet et al. (2009) reiterate this point for fish catches and related fish abundance in a more recent model of fishing effort displacement from a MPA in the North Sea. As in Hiddink et al. (2006) the local gain within the MPA is negated by fishing effort displacement into the remaining open areas. Again the management measures suggested to overcome this problem are a suite of regulations, in this instance combining area closures with reductions in total allowable catch (Hiddink et al. 2006).

5.5.5 Economic considerations

With quotas already at non-economically viable levels for many coastal fishing boats in the UK (Hansard 2002), the measures suggested by Hiddink et al. (2006) to negate the impacts of effort displacement on benthic fauna in remaining areas and regional fish stocks would appear to add significant stress to inshore fishing fleet in the UK. The economic impacts of the full scale of OWF development in the study regions and throughout Europe may have a large economic impact on fisheries if all OWFs are deemed MPAs with no fishing activity permitted.

A case study of the potential effect of initial rMCZ suggestions in the Irish Sea displayed considerable economic impacts from area closures that covered much of the existing fishing grounds (Cappell et al. 2012). Assessment suggested larger vessels would be forced to fish further afield, increasing fuel costs and safety considerations while smaller vessels would suffer the greatest impact with few alternative grounds within range. If this resulted in Nephrops tails being landed to processors outside of the currently used ports in Northern Ireland, a loss of land based jobs could be seen in these ports. This would potentially have large social and economic impacts as these ports show a very high level of dependency on fishing employment (Cappell et al. 2012). Across the three case study areas, Liverpool Bay has seen decreases in commercial fishing fleets although maintains a large fleet of rod and line angling charter vessels. The Greater Wash and Greater Thames still rely on commercial fishing to support a large number of at sea and shore based jobs (Curtis and Barr 2012; Anderson et al. 2013).

Based on the recommendations from the Regional Conservation Zone Projects and environmental, economic and social impact assessments in relation to MCZs, total area closures within OWFs may not be necessary (Defra 2012). While mobile trawls and dredges risk entanglement with wind farm infrastructure, static gears such as pots and nets may be possible to utilise within OWFs (Mackinson et al. 2006; Blythe Skyrme 2010, 2011). A ban on towed gears (mobile gears) within a designated area within Lyme Bay, UK is displaying recovery of biodiversity (Attrill et al. 2011; Sheehan et al. 2012) within the closed area. In addition the designated area is providing satisfactory fishing catches for static gears (nets and pots) with decreased risk of conflict with mobile fishing gears (Mangi et al. 2011). Artificial reef materials that augment commercially targeted species and reduce scouring of sediment at turbine bases provide a potential ecological and economic win-win that could be developed within OWFs (Jenson et al. 1994; DECC 2008; Hunter and Sayer 2009; Langhamer and Wilhelmsson 2009; Wilson and Elliott 2009). Utilising artificial reefs and selective gear closures as mitigation tools may provide sustainable benefits to static fishermen and reduce conflict between mobile gear and static gear fishermen in remaining grounds (Blyth-Skyrme 2010; Rodwell et al 2013).

5.5.6 Fishing the line, maximising benefits to static fishing activity

Static gear did not show the same reduction in effort near to OWFs as mobile gear across the case study regions, although there was limited evidence of direct benefits such as those identified in Lyme Bay (Mangi et al. 2011). Small increases in the Greater Thames region of static activity in proximity to Kentish Flats OWF and within 2 to 10 kilometres of Lynn and Inner Dowsing OWFs in the Greater Wash suggested fishing the line, whereby fishing activity is concentrated at the border of area closures (Kelly et al. 2002; Murawski et al. 2005; Kellner et al. 2007). Such behaviour can represent both real benefit from closure of areas to fishing (Murawski et al. 2005; Roberts et al. 2001; McClanahan and Mangi 2001) and perceived benefits if an area is trialled in expectation of increased catches (Leleu et al. 2012).

Fisheries economics suggest fishing activity choices to be dominated by expected economic return to individual fishermen from fishing in specific locations and using specific gears (Gordon 1953; Hutton et al. 2004). Increases in activity in the Greater Thames and possibly the Greater Wash suggest a combination of these motivating factors influencing fishing behaviour. As exact locations of catches were not available from landings data, the data set as a whole only suggests a decline in landings, masking high or low catches at specific locations. In the Thames region increased static fishing activity was only observed in the near distance category (to the Kentish Flats OWF site) post-construction. The increase however, was only due to 1 to a maximum of 2 sightings in any given year (single sightings on one or two flights, out of up to 190 flights annually). This suggests the ground was occasionally fished but catches were not high enough to invest repeated effort. However, other motivating factors, such as financial compensation from OWF developers from loss of ground must also be considered.

The attraction of fishing effort to the boundaries of year round closures identified for extensive area closures such as the Grand Banks closures in the North West Atlantic occurred in a historically rich fishing area (Murawski et al. 2005). In all three study regions the round one OWF utilised as case studies occupy peripheral fishing grounds, and occupy a much smaller area of sea bed than examples such as the Grand Banks closures. The same results as large purposely designed area closures as a result of reduced fishing area due to presence of an OWF at these sites are, understandably, unlikely. The larger round two and round three sites in each region such as Gwynt Y Mor (Liverpool Bay), Sheringham Shoal (Greater Wash) and Thanet and London Array (Greater Thames) occupy more significant fishing grounds and cover greater spatial scales (Fig 4.1 a, 5.2, 5.3). The level of effort displacement will be greater from these sites as is the potential for increased biomass of commercial species occurring within the sites. This may lead to more distinct evidence of increased fishing effort in close proximity to the site and, where permitted and practical, increased effort within the sites themselves.

5.5.7 Management and research requirements

Currently more extensive monitoring systems, especially for inshore vessels are being developed. These include the ‘Succorfish’ satellite global positioning system based tracking devices for inshore vessels which can monitor when gear is deployed and locations (MMO 2012, Marine Scotland 2013). Fishermen’s own records of their vessel tracks and grounds fished are being collated by the Crown Estate, to provide a more detailed data layer for use in OWF development and MPA network planning (Crown Estate 2011). VMS data analysis methods that incorporate log book information containing catch records have also been developed that provide more spatially explicit catch data (Gerritsen and Lordon 2011). If made available to research projects focusing on fishing effort around OWFs, these data sets would allow for the increases in static effort in proximity to OWFs suggested by the results of this study to be verified. Potential benefits to catches and static fishing activity could be quantified in greater detail, and a greater evidence base for management decisions provided. If benefits to static fishing activity and related stocks can be established through newly emerging data resources, it may be important to consider precautions for management of stocks (Mangi et al. 2011). It has also been identified as a priority to establish safety and risk procedures for vessels operating within proximity to OWFs (Department of Trade and Industry 2005).

Provision of effective habitat and augmentation of stocks, through practices such as introduction of hatchery reared lobster provide management measures, as well as mitigation for disruption of regional fishing activity (Blyth-Skyrme 2010, 2010a; Rodwell et al. 2013 2013). Habitat creation in proximity to OWFs is also an option to encourage spill over of crustacean stocks (Jenson et al. 1994; Kelly et al. 2002). Crustaceans including the commercially exploited edible crab (*C.pagarus*) and European lobster (*H.gammarus*) have shown benefits within the meta-analyses conducted in this thesis (Chapter 3). The individual studies of marine renewable energy instillations and artificial reefs show the greatest increase in abundance of these species occurs in relation to complex stone or concrete structures, containing holes or spaces (Langhamer and Wilhelmsson 2009, Hunter and Sayer 2009, Chapter 3). Recently available environmental monitoring reports from Horns Rev OWF in Denmark, Egmond an Zee OWF in the Netherlands and Lillgrund OWF in Sweden, provide evidence of these benefits extending to larger commercial fish species associating with turbine pilings and scour protection (Reubens et al. 2010, 2013; Winter et al. 2010; Stenberg et al. 2011; Lindeboon et al. 2011; Bergstrom et al. 2012).

The round one OWFs within the three study sites: Liverpool Bay, Greater Wash and Greater Thames contain no extensive scour protection (Ottensen Hansen 2005). Only small stone armouring is utilised at the points where cable J tubes pierce the sea bed (Ottensen Hansen 2005). This severely limits the available habitat that is likely to be responsible for the increase species abundance identified in other European and UK studies. In relation to both biodiversity benefits and fisheries management and mitigation, attention to the design and deployment of scour protection and armouring is of high importance (Gill 2005; Linley et al. 2007, 2008; Inger et al. 2009; Wilson and Elliott 2010). Mitigation and planning solutions to aid co-existence of fishing and renewable energy industries are reviewed in Table 5.7.

Table 5.7 Benefits and disadvantages of mitigation and management measures identified to aid the co-existence of fisheries and marine renewable energy industries.

Mitigation Measure	Description	Benefits	Disadvantages	Supporting Studies
Designing turbine bases or scour protection to enhance fisheries.	▪ Existing studies have shown increases in abundance of target species by adding complexity (holes) to concrete bases (Langhamer and Wilhelmsson 2009). Commercially important species have shown attraction to pilings and scour protection (Reubens et al., 2013; Winter et al., 2010).	▪ Potential for increase in commercially targeted stocks. ▪ Crustaceans and gadoid family fish species could be targeted by static gears which are more suitable for use in OWFs. ▪ Could provide a direct benefit for local inshore fisheries.	▪ Additional cost to developers. ▪ Testing structures may limit cost-effectiveness and time-scale of widespread application. ▪ Extensive use of ideal scour protection for species benefits may be more expensive than cheapest available material. ▪ Advantages to static gears may not be seen for mobile gear fisheries. ▪ Scour protection presents another seabed obstruction.	Mackinson et al., 2006; Ramos et al., 2006; Langhamer and Wilhelmsson, 2009; Wilson and Elliott, 2009; Wilson et al., 2010; Blyth - Skyrme 2010; Rodwell et al., 2013.
Deploy artificial reefs in remaining open grounds.	▪ Artificial reefs have been displayed to increase commercial species abundance (Jenson, 1994; Fujita et al., 1996; Jenson et al., 2000). ▪ Fishing on or near artificial reefs has been shown to return profitable landings (Ramos et al., 2006).	▪ As above.	▪ As above, although the disadvantage for mobile gear fisheries may be greater if additional obstructions are placed on the sea bed in remaining open grounds.	Jenson, 1994; Fujita et al., 1996; Jenson et al., 2000; Rodwell et al., 2013; Ramos et al., 2006.
Stock enhancement from hatchery seed / hatchery reared juveniles.	▪ Hatcheries already exist to support oyster, scallop and lobster fisheries. Mussel fisheries already rely on 'growing-on' wild stocks. ▪ OWFs present an area of restricted fishing activity for laying wild mussels, or seeding with juvenile oysters and scallops. ▪ Rock scour protection would provide habitat for hatchery reared crustaceans.	▪ Direct benefits for local inshore fisheries. ▪ Provide diversification options to 'keep fishermen fishing.' ▪ Enhance sustainability of fisheries. ▪ May reduce spatial conflict between static and mobile gear fisheries on open grounds. ▪ For lobster fisheries, seeding combined with V-notching (marking female brood stock) would aid sustainability.	▪ Offshore locations rarely used in aquaculture, presenting new challenges. ▪ Safety and risk concerns for developers over use of large vessels and dredging gear. ▪ Crustacean fisheries would ideally want to set pots close to rock scour protection, within turbine safety zones. ▪ Current hatchery production may not meet potential demand.	Mackinson et al., 2006; Langhamer and Wilhelmsson, 2009; Blyth - Skyrme, 2010; Rodwell et al., 2013; Syvret et al., 2013.
Application of Several or Regulating Orders.	▪ Several or Regulating Orders remove the public right to fish, these could be applied to OWF sites to establish a managed private fishery. ▪ Orders could be applied in association with other mitigation options such as habitat augmentation and seeding of commercial species. ▪ The aim would be to provide direct mitigation for local fisheries impacted by siting of a development.	▪ Property rights passed to a specific set of fishermen, such as those impacted by OWF siting. ▪ Good potential for sustainable management. ▪ Limited number of recognised fishermen reduce developer safety and risk concerns. ▪ May reduce spatial conflict between static and mobile gear fisheries on open grounds.	▪ By design the orders exclude some fishermen, potentially leading to conflict. ▪ Orders limited to shellfish species. ▪ Time and cost investment to establish an order. ▪ Shellfish harvesting would require a 'shellfish water harvesting classification'	Blyth - Skyrme, 2010; Rodwell et al., 2013; Syvret et al., 2013.
Co-location of OWFs and MPAs/MCZs.	▪ In the UK 127 MCZs were recommended, including 2 potential OWF co-location zones, 28 have been put into practice (JNCC 2013). There are also 108 SACs, 108 SPAs, 30 NCMPAs, 1 MNR, and SSSIs and Ramsar sites with marine components in UK seas. Co-location may limit overall spatial pressures on fishing fleets and provide potential benefits to targeted species.	▪ Minimise cumulative loss of fishing grounds. ▪ Potential benefits to habitats and targeted stocks. ▪ Fishermen / vessels could be involved in monitoring. ▪ Infrastructure provides a visible mark of MPA location.	▪ Fishermen may want to retain access to grounds within OWFs. ▪ Presence of an OWF may negatively effect MPA objectives.	Mackinson et al., 2006; Langhamer and Wilhelmsson, 2009; Wilson and Elliott, 2009; Wilson et al., 2010; Blyth - Skyrme 2010; Reubens et al., 2013; Rodwell et al., 2013.

Mitigation measure	Description	Benefits	Disadvantages	Supporting studies
Co-location of OWFs and aquaculture facilities	▪ Integration of aquaculture facilities within OWFs has would limit spatial pressures amongst marine activities (Buck et al., 2004; Buck and Krause, 2012; Syvret et al., 2013; MMO 2013b)	▪ Minimises cumulative loss of fishing grounds. ▪ Provides employment opportunities for vessel owners.	▪ Safety and risk concerns of developers. ▪ Offshore aquaculture is a developing industry with successful practices under development. ▪ May reduce ease of access for engineering and maintenance of turbines.	Buck et al., 2004; Buck and Krause, 2012; Syvret et al., 2013; MMO 2013b
Financial or equipment aid	▪ Fuel subsidies to mitigate for increased travel time, or subsidies to allow fishermen to diversify equipment to target alternative fisheries provide direct mitigation for lost fishing opportunities. ▪ Direct financial compensation for lost catches is also widely used.	▪ Directly approaches financial concerns. ▪ Applicable to all fishermen and fisheries.	▪ Potential for conflict as subsidies and compensation may not be evenly distributed. ▪ Promotes continued fishing in remaining grounds, potentially creating unsustainable resource exploitation.	Mackinson et al., 2006; Blyth - Skyrme 2010,; Rodwell et al., 2013.
Clear information on fishing regulations	▪ Information on exactly what fishing activity is permitted and where within OWF sites was identified as lacking by fishermen in the UK (Blyth-Skyrme 2010; Rodwell et al., 2013). ▪ Clear communication and publication/sharing of information would potentially reduce fishermen's perceived need to fish elsewhere.	▪ Direct communication between developers and fishermen's representatives could identify which fishing activities are permitted. ▪ Information could be made easily accessible through industry updates provided by industry representative organisations (such as Seafish in the UK).	▪ Clear and well recorded communication, possibly with legal representation present, would be beneficial to ensure regulations are clear and suitable to both parties.	Mackinson et al., 2006; Blyth - Skyrme 2010; Rodwell et al., 2013.
Clear safety information and protocols	▪ As above, clear information on protocols and repercussions if fishing equipment becomes entangled on OWF infrastructure are required to reduce perceived need to fish elsewhere. ▪ Safety protocols and agreed action for accidents within OWFs are also identified, particularly with risks to vessels from collision with pilings or capsize if trawls become entangled. ▪ Identification and charting of new hazards and exact location of infrastructure and debris on seabed are required in development zones.	▪ As above, although discussions also need to involve coastguards, RNLI and emergency services.	▪ Clear well recorded communication, with legal representation to record proceedings and outcomes would be required.	Mackinson et al., 2006; Blyth - Skyrme 2010; Rodwell et al., 2013.
Improved monitoring / data collection on location of fishing grounds	▪ Siting of OWFs and selection of areas to be leased by Crown Estate in the UK have led to some OWFs being located on fishing grounds. ▪ Earlier communication and use of fishermen's suggestions for ideal siting would provide mitigation and reduce loss of ground and displacement effects at the earliest planning stage.	▪ Reduces negative effects of displacement before OWF is constructed. ▪ Improved vessel monitoring systems for vessels under 15m and application of fishermen's own activity data (plotter data).	▪ Current monitoring data, particularly for vessels under 15m does not provide detailed evidence of important grounds and activity. ▪ Commercial sensitivity of monitoring data limits potential application to evidence gathering and research opportunities.	Mackinson et al., 2006; Blyth - Skyrme 2010; Crown Estate 2011; Rodwell et al., 2013; Turner et al., 2015; de Groot et al., 2014.

○→● *5.6 Summary*

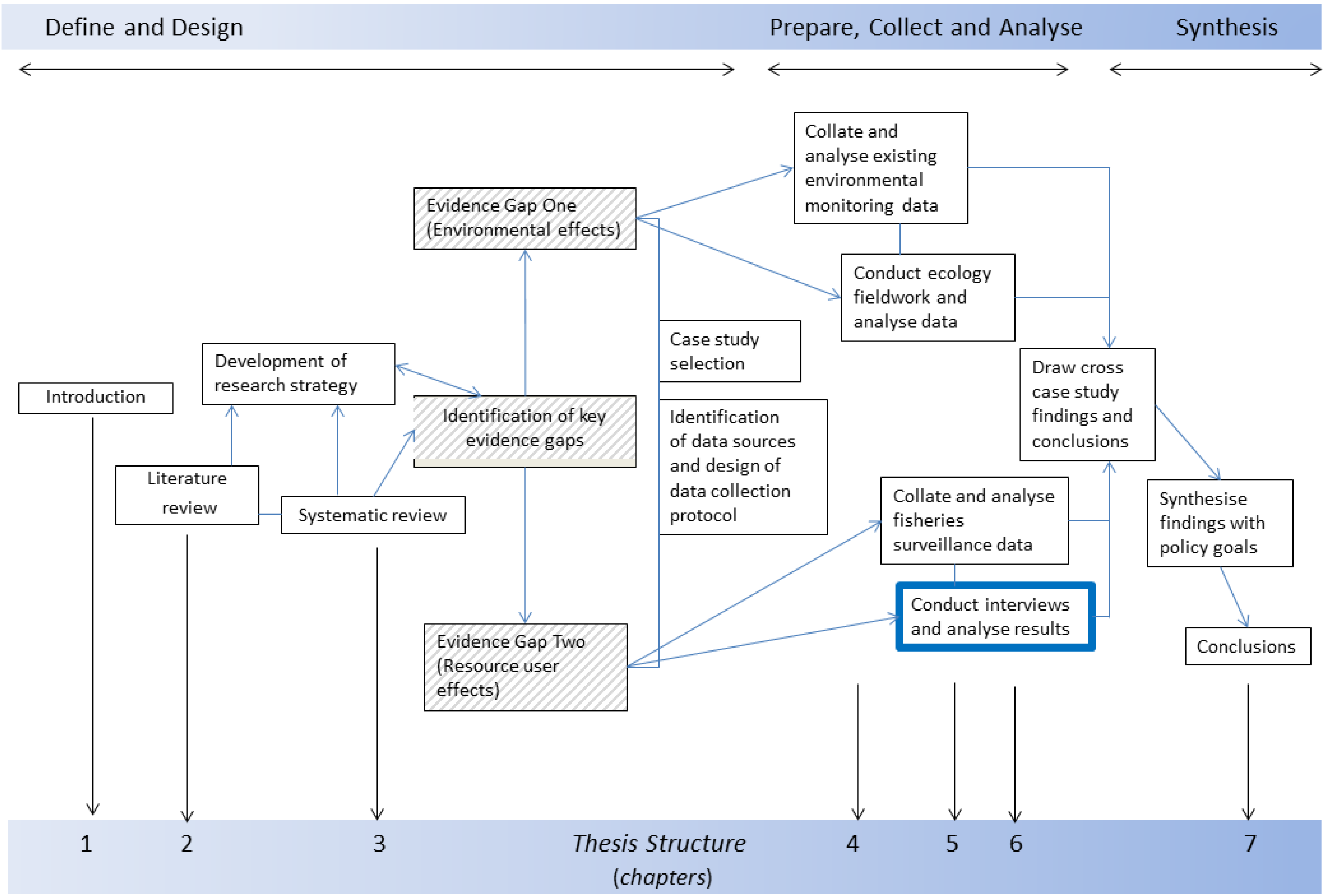
This chapter investigated the hypothesis that: 'presence of OWFs will lead to increases in catches and fishing effort in proximity to OWF sites.' Investigating this hypothesis aimed to identify if fishing grounds were lost, or gained, and if fishermen exploited ground within proximity to OWF structures as a result of OWF deployment. The chapter also aimed to identify if ecological effects on individual species, identified in earlier chapters, were apparent in spatial distribution of fishing effort and fishery landings data.

- The use of three different spatial activity data sources suggested fishing activity from mobile gears decreased close to OWFs post-construction.
- Spatial activity data for static fishing practices displayed smaller decreases in activity or even increases, although activity within OWFs was not observed.
- A general national decrease in fishing activity and numbers of registered vessels indicated decreases in effort may reflect national trends. As decreases in fishing effort were greater near OWFs than at greater distances from operating OWFs, effort displacement was likely but limited existing fishing activity at Round One OWFs pre-construction prevented obvious trends being identified.
- Other factors such as policy, management or environmental changes were noted to potentially effect fishing activity and are investigated further in fishermen interviews, discussed in the following chapter (chapter 6).
- The level of detail required to fully address these factors was limited by restrictions on data release due to commercial sensitivity issues.
- Landings data were limited to ICES rectangle scales and not possible to link to vessel activity as no vessel identifiers were permitted in the sightings data.
- Without log book data to attribute landings to vessel positions and VMS data and landings data containing vessel identifiers, locations of individual catches were

unobtainable (Gerritsen and Lordon 2011). Therefore, changes in landings could not be attributed to OWF construction, as only very broad-scale effects would have been identifiable at this scale (Walker et al. 2009).

Confidence was limited in the statutory aerial surveillance data sets for under 15m vessels. As smaller vessels typically fished the inshore grounds the case study OWFs were constructed within, fishermen's mapping of activity through interviews provided a useful additional data source. The development of more detailed inshore vessel monitoring through technologies such as 'Succorfish' (MMO 2012; Marine Scotland 2013) and the collection of fishermen's personal activity data from vessel chart plotters (Crown Estate 2011), will provide important future data source to assess effects of OWF on fishing activity. The present data sources, including the most detailed (VMS data), have identifiable weaknesses for monitoring fishing activity at high spatial and temporal resolutions (Wilen and Abbott 2006; Vanstead and Silva 2010; Lambert et al. 2011). The existing surveillance data sets are currently being adapted from enforcement purposes to suit detailed ecological and economic studies. The need for data that can provide more accurate representations of actual fishing activity and catches has been recognised as being a priority by academics, marine planners and the fishing industry (Rodwell et al. 2013; deGroot et al. 2014; Turner et al. 2015).

Recognition of the need for more accurate data on use of the sea has become more apparent as demands on space for economic activities has increased as a result of OWF development and marine protection (Crown Estates 2012; Rodwell et al. 2013). Since Mackinson et al. (2006) recorded fishermen's perceptions of the effects of OWF development on fishing activity in 2006, OWF developments have progressed rapidly. The enactment of the Marine and Coastal Access Act in 2009 has led to a network of MPAs being researched, and recommendations for locations of marine conservation zones have been released (JNCC 2013). The demands OWFs and MCZs have placed on available space for marine activities, particularly fishing has led to the requirement for a system of marine planning (Ehler and Douvere 2009; Christie et al. 2013). The following chapter utilises similar semi-structured interviews methods to Mackinson et al. (2006). The interviews investigate fishermen's experiences and perceptions of the effects of OWFs on fishing activity and catches in 2011. In 2011, 11 round one OWFs were present, larger round two sites were under construction and the largest, round three sites had been announced. The interviews provided the opportunity to investigate the effect of OWFs in relation to other policy, management and environmental issues. Interview's also approached fishermen's perceptions of potential planning solutions to achieve ecological and economic objectives of marine plans (including the objective of ensuring existing economic activities can continue).



Define and Design
Prepare, Collect and Analyse
Synthesis
Collate and analyse existing environmental monitoring data
Evidence Gap One (Environmental effects)
Conduct ecology fieldwork and analyse data
Case study selection
Development of research strategy
Draw cross case study findings and conclusions
Introduction
Identification of key evidence gaps
Identification of data sources and design of data collection protocol
Literature review
Systematic review
Collate and analyse fisheries surveillance data
Synthesise findings with policy goals
Conduct interviews and analyse results
Evidence Gap Two (Resource user effects)
Conclusions
1
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Thesis Structure (chapters)
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7

Chapter 6. Resource User Experiences and Perceptions

Fishermen's perceptions of the effects of OWFs on fishing activity and catches, including best management options.

6.1 Introduction

Direct resource user face to face interviews have been utilised extensively in understanding fishermen's effort distribution, and in gaining information on the effect of new developments, management measures and ecological changes (Bene and Tewfik 2001; Daw 2007; Hall and Close 2007; Daw 2008; Hall et al.. 2009; Daw 2010; Hind 2011). Fishermen interviews are also widely used in regions where little or no surveillance data exists, including for inshore under 15 m fleets in the UK (des Clers et al. 2008; des Clers 2010).

Evidence on the effect of OWF developments from fishermen's experience of changes in catch and fishing practices provides a direct account of ecological changes, economic effects and knock on effects of effort displacement. As fishermen are working on the sea on a daily basis, recording their experience and knowledge provides a rich source of information on changes in ecology, and subsequent changes in fishing activity (Close and Hall 2006; Hall and Close 2007; Daw 2008; Hind 2011). Fishermen's experience and knowledge has to be interpreted in a different manner to purely objective data, such as surveillance and landings data. Scientific surveys aim to order reality through quantitative scientific method (Close and Hall 2006). Fishermen's knowledge and experience provides a more quantitative, informal world view, where humans are involved with the environment they work, as an intricate part of the natural world (Berkes 1993; Gadgil et al. 1993; Close and Hall 2006).

Recording fishermen’s knowledge and experience provides a means of interpreting the trends seen in activity and landings data (Hall and Close 2007). This process also records the rationale behind spatial activity (Bene and Tewfik 2001). Fishermen are observing ecological, environmental and anthropogenic changes on a daily basis, often when scientific surveys are not present (Close and Hall 2006). Utilising catch and landings data alone is often criticised by fishers as results from analysis of this data are a product of regulations, not actual species occurrence and abundance (Johnson and van Densen 2007). The integration of both approaches in this thesis (analyses of statutory surveillance data and analyses of interview responses and activity mapping from local fishermen) provides a complete assessment of effects of OWF development on regional fishing. As yet there has been little attention on the effect of OWFs on fishing activity, beyond required liaison from OWF developers. This chapter aims to use resource user interviews to identify the effects of OWFs amidst other social, economic and environmental pressures on fishing activity and catches. This chapter will gather fishermen’s perceptions on the best management and mitigation approaches to ensure fishing, renewable energy and marine conservation objectives can be achieved. The work aims to complete the set of studies undertaken within the thesis to provide information on the effects of OWFs, to aid MPA co-location designation decisions and marine planning.

Fishermen’s responses to changing developments, biological, economic and regulatory conditions and subsequent decisions where to allocate effort are important to understand in resource management (Opaluch and Bockstael 1984). Gaining understanding of this type of behaviour is often a complex process as fishermen’s decisions can be influenced by a wide array of biological, social and economic factors (Hilborn and Waters 1992). This process incorporates many factors beyond simple appreciation of the greatest economic return

(Gordon 1953), especially as few fisheries are open access. This is especially true in the Irish Sea and North Sea, where area restrictions due to other activities, limits on activity from quotas administered through the Common Fisheries Policy and national licenses, affect all fisheries (Daw and Gray 2005). The changes in fishing spatial activity identified in Chapter 5 cannot attribute changes solely to factors related to OWFs, but must take into consideration other factors. Other factors may include a range of pre-existing biological, social and economic factors from anthropogenic activity (e.g. dredging, oil and gas extraction) to regulations such as quota restrictions.

Chapter 5 investigated the hypothesis that: 'Presence of OWFs will lead to increases in catches and fishing effort in proximity to OWF sites.' (Null hypothesis – Presence of OWF will not effect catches and fishing effort in proximity to OWF sites). This hypothesis is also investigated through interviews in this chapter, with fishermen questioned directly if they have experienced increases in activity and catches in proximity to OWFs. The interview methods also provided opportunity to investigate responses further, asking exactly what changes were experienced, and what other factors may have led to change, or no change, being experienced in the region. Potential management solutions were also investigated through interview questions.

The first objectives of this chapter are therefore:

- Objective 1. Record fishermen's knowledge and experience on the effect of OWFs on fishing activity and catches and analyse if there are regional differences or differences between fishing practices (mobile or static gear) in responses.

- Objective 2. Record fishermen's perceptions on exactly what factors related to OWFs have caused observed trends and what pre-existing factors may be affecting activity. Responses were analysed to identify if regional, gear type or social factors influence responses.
- Objective 3. Record fishermen's experience of changes in abundance of specific species and ascertain if any changes are perceived to be related to OWF factors or other factors.

In a study during the earliest phase of OWF development and planning Mackinson et al. (2006) recorded fishermen's perceptions of the effects of OWFs on fishing. Certain positive and negative effects were perceived at this time. Further objectives of this chapter are therefore:

- Objective 4. Identify through interviews in 2011 if positive and negative effects perceived in surveys conducted by Mackinson et al. (2006) have come to pass. Responses were analysed to identify if region, gear type used by fishermen or social data explain patterns in responses.

Marine planning policies and MCZ objectives identify fishing as a key activity that should be supported to continue in a legal and sustainable manner (HM Government 2011; JNCC 2013; Defra 2013). Interview survey techniques to record fishermen's experience and local knowledge have been developed to incorporate fishermen's knowledge in resource management decisions (Close and Hall 2007; des Clers 2010; Hind 2012). Fishing industry input, as one of 11 key existing marine activities in the Marine Policy Statement, is also required for consideration in social and economic assessments of rMCZs and Marine Plans

(HM Government 2011; JNCC 2013; Defra 2013). Furthermore the presence of working fisheries in a region may add to the social and cultural value of a region (Urquhart and Acott 2013). The presence of working fisheries is identified to provide a connection with tourist's expectations and sense of place in coastal towns (Urquhart and Acott 2013). The attraction of tourists and provision of at sea and shore based jobs provides important economic support, especially in regions with limited industry and employment opportunities (Beatty et al. 2010; Cappell 2011). Ensuring legal and sustainable fisheries can continue in a region is therefore important to wider social, economic and cultural objectives of marine plans (HM Government 2011; JNCC 2013; MMO 2013b). In relation to this the final objective of this chapter is to:

- Objective 5. Record fishermen's perceptions on management and mitigation requirements to ensure fishing, renewable energy and marine conservation can co-exist successfully in a region. Responses were analysed to identify if region, gear type or fishermen's social data explain patterns in responses.

A mixed-methods survey was utilised in this study, to combine analytical analysis and systematic analysis to provide a more holistic view of the reasons behind changes seen in fishing activity, and understand these in relation to the wider socio environment (Bene and Tewfik 2001; Daw 2008). Analytical approaches are used to break down activity and catch patterns into separate elements, to create cause and effect explanations to understand the effect on activity as a whole. Systematic analyses are used to consider mobile and static fisheries and regional fisheries in totality, and identify the interactions between existing components and the addition of OWF development.

The approach suffers the risk of bias and interviewees incorporating personal agendas (Oppenheim 1966). Individual perceptions must be interpreted with appreciation of the effect of human memory and perspective (Daw 2010). Despite these drawbacks the open-ended approach to interview questions in addition to closed question sections provides detail that will aid interpretation of the spatial activity data (Chapter 5) (Bene and Tewfik 2001).

Multivariate statistical techniques have been applied to analysis of coded themes arising from open-ended interview question responses. These techniques provide an objective assessment of responses between fishermen operating different gear types (mobile and static) and fishermen in different OWF development regions as well as incorporating individual social and economic factors (Green 1975; Blyth et al. 2002).

6.2 Methods

6.2.1 The case study areas

Interviews were conducted in the three case study areas utilised in the study of spatial fishing effort distribution and landings changes following OWF development. Detail on these case study regions, Liverpool Bay, the Greater Wash and the Greater Thames are given in Section 5.2) (Figs 4.1a, 5.2, 5.3). Similar OWF developments have occurred in each of the case study regions. The fishing practices however, differ in each region. Limited mobile or static commercial fishing activity was present in Liverpool Bay but a charter angling fleet is present. The Greater Wash region contains large fishing fleets working from Kings Lynn and Boston beam trawling for shrimp and dredging for cockles and mussels. Vessels operating out of North Norfolk ports utilise parlour pots for crab and lobster. In the Greater Thames region a mixed fleet of otter trawl vessels, drift netting vessels, crab and lobster potting vessels and oyster fishing vessels operate out of Kent and Essex ports (Mackinson et al. 2006; MMO 2011; Regional IFCAs pers. comm.).

6.2.2 The survey

Surveys were conducted face to face as a semi-structured interview, in each of the three case study regions between June and September 2011. A mixed-methods survey was developed that incorporated closed and open ended questions, following mapping of fishing activity before and after OWF construction. The interview focused on discovering if fishing activity (location and catches) had changed, and the reasons behind these changes. The interview also approached the issues arising and potential planning solutions to aid these. The interview was pilot tested, face-to-face with six fishermen of different ages (45-65), using different gear types (angling, mobile and static gears) in three separate regions (Hayle, North Cornwall, Lyme Bay, Dorset and Liverpool Bay, North Wales) and revised based on respondents comments.

Closed questions required respondents to select answers on a scale of pre-selected responses. Open ended questions provided fishermen the opportunity to elaborate on the perceptions and reasons behind closed question responses and share the points they felt were important (Bunce et al. 2000). Closed questions approached direct economic and practical effects such as fuel costs, time spent fishing and income from fishing. Closed questions requested increase, decrease or no change as answers (3 point Likert scale), or selection along a five point Likert scale (between strongly disagree and strongly agree), in reference to question responses. Closed and open ended questions addressed particular effects of OWF related to MPA benefits, such as increase in target species in surrounding areas and changes to daily activity. Questions also examined whether perceptions recorded by Mackinson et al. (2006)

had been experienced by fishermen and asked fishermen's perceptions of the best planning scenario to accommodate OWFs, MPAs and fishing activity (See Appendix 2 for questionnaire). The principal topics covered in the semi structured interview, in relation to the studies objectives were:

1. Trends in fisheries catches in last 10 years (Objective 1)
2. Impacts of OWFs on fishing activity and catches (and reasons) (Objective 1, Objective 2)
3. Other factors affecting fishing activity (and reasons). (Objective 2)
4. Ecological effects (changes in species abundance) (Objective 3)
5. If effects perceived in 2006 have been realised in 2011. (Objective 4)
6. Management / mitigation requirements to aid fishing, renewable energy and marine conservation objectives to co-exist. (Objective 5)

Interviews were recorded on a digital voice recorder. Key points made in reference to open-ended questions or information requested to be added by interviewees were recorded by hand on the interview script, as were values and answers to close ended questions (circling response). One section required the interviewee to map fishing locations before and after OWF construction on a reproduction of a regional nautical chart. This was done by hand by the interviewee, with guidance from the interviewer (MA) if required. During open-ended questions, prompts were used if necessary to maintain focus on the question subject. All interviews were conducted by the principal researcher (MA). Each interview lasted between thirty minutes and one hour. After the interview was complete additional key points and general notes were recorded on the interview script to aid data processing and analyses. Interviewed fishermen were provided the opportunity to review answers and were reminded that they had the right to withdraw information at a later date.

6.2.3 Identifying populations and interview samples

Fishing industry representatives, primarily the chief contact for Fishermen's Associations in each region, were contacted prior to visiting regions to arrange interviews. The regional Inshore Fishing and Conservation Associations (IFCAs) relevant to each study area were also contacted. Meetings were arranged to provide details on the fishing fleets operating in each region. MMO vessel lists for each region were reviewed to identify the number of vessels registered to home ports in each case study area (Table 5.1; MMO vessel lists 2011). Vessel list numbers were discussed with IFCA and fishermen's association representatives to identify the realistic number of active vessels, to gauge appropriate sample sizes.

Following contacting and interviewing leading representatives of local fishermen's associations, further contacts were sought for interviews. Individual vessel skippers were then approached in person or by phone to arrange face to face interviews. Fishermen were also approached at dockside when returning from trips or working on vessels. Charter angling vessels were identified from commercial advertisements, on UK sea-fishing online resources and contacted directly. To ensure as many relevant fishermen as possible were contacted, both commercial and charter boat operators were also requested to pass on details of other local vessel owners and operators who would be available for the survey.

The interview process aimed to attain a representative sample through pursuing interviews with all available fishermen in each region. This snowballing approach was utilised in each study area, until as many respondents as possible were sought or all active fishermen had been interviewed. If the number of interviews possible were very high and the same statements were being repeatedly gathered after a number of interviews within a sample (deemed the saturation point (Oppenheim 1966, 2000)), it was considered an option to limit samples at that point. Snowballing until all available fishermen had been interviewed was the preferred method, as novel views may be missed by deeming a saturation point in responses for this study. Fishermen approached directly or at dock-side all agreed to be interviewed. As numbers of active fishermen in each region were limited, the snowballing method was utilised, apart from in the Greater Thames region where time and resource constraints limited the number or interviews (without saturation point being reached). Results were still included for this region, but are recognised as limited by the small sample size. It is acknowledged that further interviews from regions not experiencing OWF development would have also aided interpretation of existing pressures on the industry, and their effects on activity and catches. This process was also limited by time and resource constraints.

6.2.4. Data Analyses

Each interview was given a numerical identifier and this was noted on the interview script. The date and location of each interview, vessel size, gear type used and years that fishermen have been fishing were then entered into the database.

Data from both closed and open-ended questions were entered into the database following transcription and coding, to represent responses in numerical terms to aid analysis. Closed questions were provided with a numerical value representing the response (i.e. strongly disagree = 1 strongly agree = 5) to allow simple entry into the database. For open ended questions notes were taken of key points during the interview. The interviews were also voice recorded and the recording transcribed. Transcribed responses were then reviewed for all interviews in the software package NVIVO 9. For each open ended question, responses were separated into emergent themes (coding frames) (Oppenheim 2000; Ryan and Bernard 2003). Coding themes were allowed to emerge inductively from the data without prior assumptions about categories (Daw 2008).

Short references were created and noted for each coding frame and numerical codes were matched to each coding frame (theme). In cases where a large and varied number of responses occurred, broad themes were introduced. Broad themes contained more detailed frames within them, to accommodate the full range of responses. Responses to both closed and open ended questions were summarised in tables (MS excel), and percentages of respondents from the total sample of each gear type (mobile or static fishermen) in each category location (survey area), raising each coding frame, were allocated.

Data from questions relevant to objectives 1-5 were summarised in tables and associated figures to provide a description of responses. To investigate the data more thoroughly, PRIMER 6 statistical software was utilised for the main three open ended question responses, ‘how have OWFs affected activity and catches?,’ ‘What existing activities effected activity and catches in this region?,’ and ‘What is the best planning scenario to accommodate OWFs, fishing and MPA networks?’ Each fishermen interview was treated as a unique sample and each coding frame (theme) was treated as a variable. The data provided presence and absence responses, which could be objectively analysed in PRIMER 6. Where a fisherman had identified a coding frame in interview responses, that coding frame was provided the value 1 as present. All other non-identified coding frames were given a 0 value as absent.

Bray-Curtis similarity matrices were then calculated for each dataset and non-metric multi-dimensional (nMDS) scaling plots created, to visualise the similarity and separation between fishermen’s responses. Plotting coding frames as vectors on the plots provided an indication of the variables responsible for separating responses. Interviewee factors: location, gear type, age of fishermen and vessel length were investigated through the BV step BEST statistical procedure, to identify which factor, or combination of factors best described the pattern observed in the samples. Pearson correlation coefficients were calculated for the relationship between factors and combinations of factors, with the pattern observed in separation of interview responses. The SIMPER procedure was then undertaken to identify the contribution of the different coding themes (variables) to the factors best representing the pattern identified in the data. Although this approach assumes fishermen have not experienced or perceived other coding frames (e.g. effects from OWFs, or viable planning scenarios not mentioned), it provides a statistical method to explore the data objectively. Fishermen's interview responses were later discussed to provide a broader interpretation of responses.

6.3 Results

6.3.1 Fishermen interviewed

The total 37 respondents across the three survey regions consisted of 18 mobile gear fishermen and 19 static gear fishermen. The large majority of vessels were under 10m, with only one vessel over 15m surveyed. Fishermen from the full range of age categories (18 to over 61) were interviewed, although a greater number of fishermen interviewed were over 40 (Table 6.1). All fishermen approached agreed to complete the interview, as some questions appeared to ask for repetition of information some interview questions were not answered by all respondents. All available fishermen (during site visits) were interviewed in Liverpool Bay and Greater Wash study regions. Limited time and resources in the Greater Thames region prevented all available fishermen being interviewed. The smaller sample was retained as the interview methods provide detailed insight into the region, and add to the national level data sets.

Table 6.1. Fishermen interviews conducted by region including the principle gear type used, vessel size, age and experience of interviewees.

		Vessel size		Gear type		Demographics			Experience	
Case study region	Total No. Interviews	Vessels under 10 meters	Vessels over 10 meters	No. using static gear	No. using mobile gear	Fishermen aged 18-40	No. aged 41-60	No. aged 60+	< 20 years experience	> 20 years experience
Liverpool Bay	13	10	3	9	4	3	5	5	3	10
Greater Wash	19	9	10	10	9	5	8	6	4	15
Greater Thames	5	5	0	0	5	3	1	1	3	2

6.3.2 Background to fishing within regions

Fishermen's individual knowledge was the primary reason behind the choice of fishing ground location for all fishermen interviewed. Weather conditions, target species behaviour, and travel time were also provided as reasons dictating choices (Figure 6.1).

89% of static fishermen interviewed and 82% of mobile fishermen reported that catches had decreased over the last 10 years. In addition to OWF development, effects of climate change, overfishing, oil, gas and aggregate extraction were also suggested as possible factors leading to this decline (Figure 6.2). Results were from a small sample in relation to all vessels fishing in UK waters. This provided a limited view of the experiences of all fishermen which is important to consider in interpretation of these results.

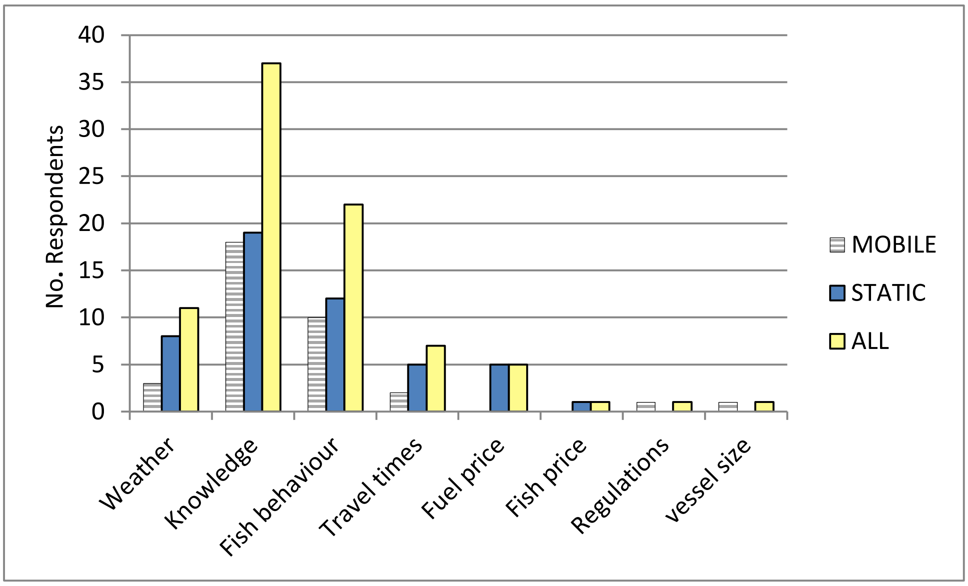


Figure 6.1 Interview responses to the question of 'factors influencing fishermen's choice of locations fished.'

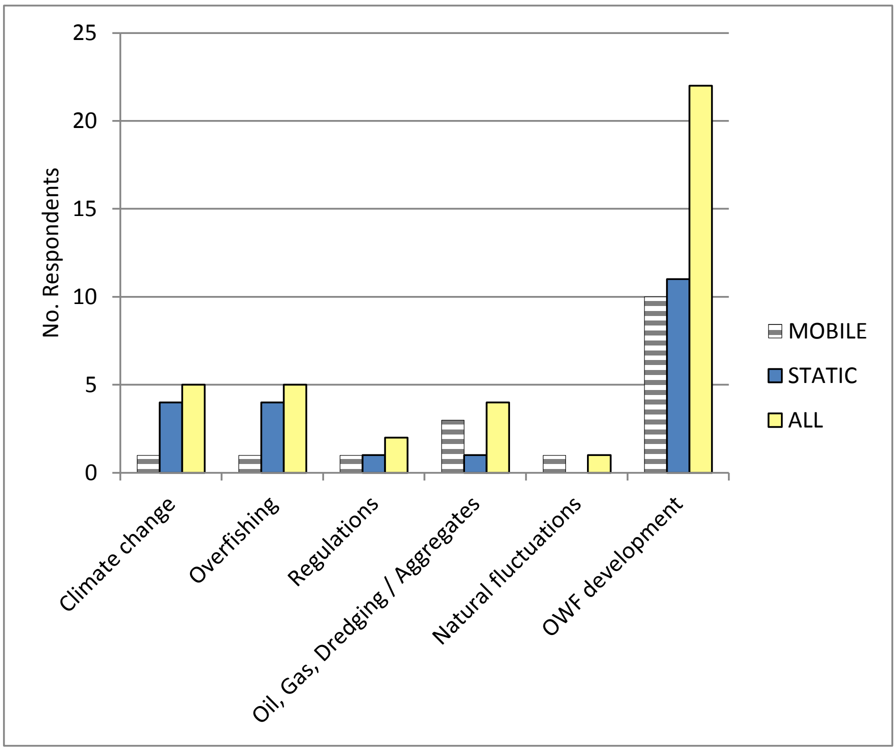


Figure 6.2 Fishermen's perceptions of factors leading to changes in catches observed in the local region over the past 10 years.

6.3.3 Effects of OWF development on fishing activity and catches (Objective 1)

Combined results

When results from each of the case study areas were combined to provide a national level representation, separate effects from OWFs were identifiable between mobile and static gear fishermen's responses. The majority of mobile gear fishermen attributed a change in their fishing activity patterns to OWF development (83% of mobile gear fishermen). A smaller percentage of static gear fishermen suggested OWFs had affected activity patterns (58%). Responses to the question of whether OWF development had affected catches displayed a similar separation between mobile and static gear fishermen. Mobile gear fishermen generally perceived a change in catches as a result of OWF development (67%). Responses from static gear fishermen were much more variable: 47% perceived a change in catches in relation to OWF development, 42% were unsure if a change had occurred or could be related to OWF development and 11% perceived no change in relation to OWFs (Table 6.2a).

Species perceived by respondents as increasing in catches in relation to OWFs were brown crab (*Cancer pagarus*), European lobster (*Homarus gammarus*), juvenile cod (*Gadus morhua juv*.) and juvenile whiting (*Merlangius merlangus*). Species perceived as decreasing in catches were dominated by flatfish (plaice, *Pleuronectes platessa* and sole *Solea solea*) and rays, (thornback ray, *Raja clavata*, *Raja spp*.). Cockles (*Cardiidae spp*.) were also indicated as decreasing (Table 6.2b).

Table 6.2 a) Fishermen's perceptions of relationship of OWFs to changes in their activity and catches, b) Species perceived as increasing or decreasing in presence, in relation to OWFs.

a)

	Fishermen n=37	%	Mobile n=18	Static n=19
Fishing activity has changed due to OWFs?				
Strongly agree	11	30	8	3
Agree	15	41	7	8
Not sure	4	11	2	2
Disagree	7	19	1	6
Strongly disagree	0	0	0	0
Catches have changed due to OWF?				
Strongly agree	12	30	7	5
Agree	8	24	5	3
Not sure	11	30	3	8
Disagree	5	14	3	2
Strongly disagree	0	0	0	0

b)

	Fishermen n=37	%
Species displaying Increase?		
Brown crab and lobster	7	19
Starfish species	4	11
Cod and whiting	7	19
Whelk	2	5
Decrease?		
Rays	11	30
Sole	9	24
Shrimp	5	14
Cockles	4	11
Bass	3	8
Mussel (beds)	3	8
Velvet crab	1	3

6.3.4 OWF related factors perceived to influence activity and catches (Objective 2)

Lost fishing grounds dominated the factors that influenced changes to fishing activity and fish catches for both mobile (67%) and static gear fishermen (53%). In relation to influence on catches, physical disturbance from construction, especially due to pile driving (33% mobile, 32% static) and noise during operation were raised by the majority of mobile and static fishermen. A high number of static fishermen also perceived the possible effects of electric and magnetic fields (52%) and siltation (32%), as influencing changes in fish and shellfish distribution and therefore catches and activity (Table 6.3). The percentage of fishermen within each region identifying certain effects (identified through coded themes), show different effects were of greater relevance in certain regions (Figure 6.3). It is important to consider that the small sample size in the Greater Thames region gave greater weight to individual fishermen's responses in that region.

Table 6.3 Fishermen's responses to 'How OWFs may have influenced activity and catches.'

	Fishermen n=37	%	Mobile n=18	Static n=19
How have OWFs changed activity and catches?				
Lost ground	22	59	12	10
Pile driving	12	32	6	6
Electric and magnetic fields	12	19	2	10
Noise	11	28	6	5
Siltation	9	24	3	6
Changed fish behaviour	7	19	4	3
Gear conflict	6	16	4	4
Gear obstruction	5	14	3	2
Increased fuel cost / steaming	4	11	3	1

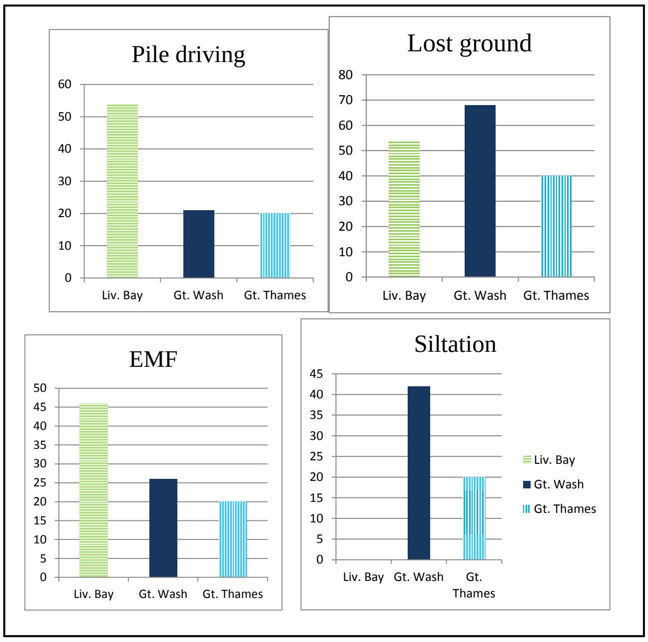


Figure 6.3 Percentage of fishermen within each region (Liv. Bay horizontal stripes, Gt. Wash solid shading, Gt. Thames vertical stripes) identifying each of the top themes in interview responses relating to OWF influence on activity and catch.

The non-metric multi-dimensional scaling plot of the Bray Curtis similarity matrix of untransformed presence absence data, for responses to themed and coded interview data exposed separation between locations and gear types (Fig 6.4). The BV Step best procedure revealed the combined factors, gear type (mobile or static) and location (case study site); best explained the pattern in coded themes of responses across all interviews. The correlation was still low (0.119), suggesting a large degree of overlap between responses of fishermen across these groups.

Overlaying of vectors (representing coded themes) on nMDS plots displayed the influence of coded themes on the separation between individual fishermens responses (Figure 6.4). Vectors overlaid on the nMDS indicate how each theme influenced the separation within the nMDS. The vectors demonstrated different themes were more prevalent in certain regions.

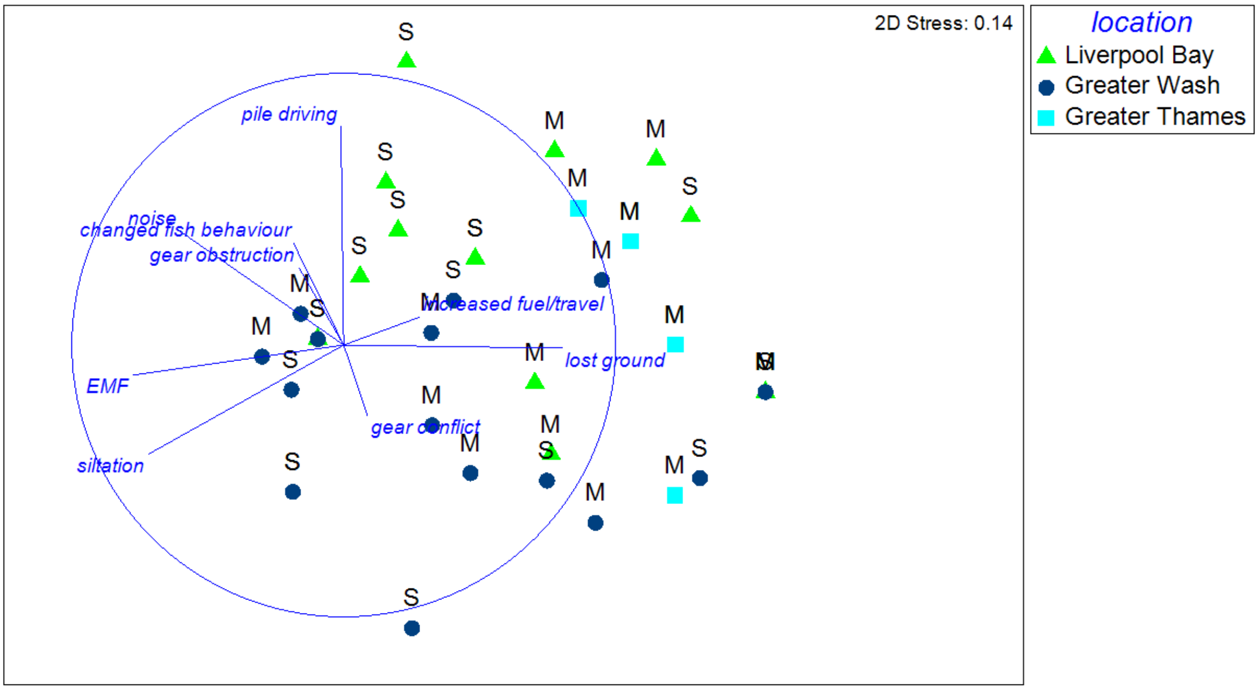


Figure 6.4 nMDS plot of Bray Curtis similarity matrix calculated from presence absence data of themes in individual interview response data from the question of OWF related factors perceived to influence activity and catches. Each fisherman interviewed is represented by region; Liverpool Bay (triangle), Greater Wash (circle), Greater Thames (square) and gear type used; mobile (M) or static (S). Vectors refer to the themes identified across all interviews.

Siltation and gear conflict appear to be raised more often as having an effect on activity and catches in the Greater Wash study region. Increased travel times, fuel costs and effects of pile driving appear to influence responses in the Liverpool Bay region. Lost fishing grounds appeared as an affect across all regions. The clustering of vectors for pile driving, noise and changed fish behaviour, suggests these themes were all identified in the same interviews from a small number of mobile gear fishermen in the Greater Wash and Liverpool Bay regions. Increased fuel/travel and lost ground also appear related, suggesting both themes were raised within some of the same interviews (Fig 6.4).

The SIMPER procedure displayed the coded themes contributing the highest percentage to the dissimilarity between locations were changed fish behaviour and sedimentation between

Greater Wash and Greater Thames (16.2% and 15% contribution respectively to an overall average dissimilarity of 67.4%). Sedimentation was raised more often in the Greater Wash region, whilst changed fish behaviour was raised more often in the Greater Thames region. Pile driving and sedimentation contributed most to the dissimilarity between the Greater Wash and Liverpool Bay region. Increased travel was a greater issue in the Thames region, with a 16.2% contribution to overall dissimilarity. EMF effects were a greater concern in Liverpool Bay with a 15.2% contribution to an overall average dissimilarity between these locations of 62.5%. Sedimentation was again raised more often in the Greater Wash whilst pile driving was raised more often in Liverpool Bay. Between the Greater Thames and Liverpool Bay increased fuel and travel, as well as EMF had the greatest contribution (16% and 15.6% contribution respectively, with an average dissimilarity between locations of 57%). The different nature of the fisheries in each region may explain some of the separation seen. Harvesting of cockles and mussels, and potting for crab dominates fisheries in the Greater Wash. Fishermen in this region reported reductions in cockles and mussels that they attributed to suspended sediment. Analyses of existing factors in the following section highlights this has been a long standing concern in the Greater Wash. These existing concerns may possibly have influenced responses.

The coding themes contributing the highest percentage to the dissimilarity between gear types were lost fishing grounds and EMF. Loss of fishing grounds was identified by a greater number of mobile gear fishermen, whilst EMF was identified by a greater number of static gear fishermen, especially angling charter boat operators (15.6% and 14.6% contribution to dissimilarity respectively with an overall average dissimilarity between gear types of 62.96%). Angling charter boat operators in Liverpool Bay reported distribution of catches of elasmobranchs had changed. Two fishermen reported elasmobranchs were no longer caught in gullies within the south east of North Hoyle OWF, but now appeared in greater abundance in shallower inshore regions. Two fishermen operating smaller inshore trawlers reported large declines in catches of adult flatfish. Although all interviewees accepted there was limited supporting research, they questioned the influence of EMF as a cause of this change.

6.3.5 Existing factors influencing fishing activity and catches (Objective 2)

Fishermen across all regions repeatedly identified a number of existing factors that effected their fishing activity patterns and catches. Different factors were identified by static and mobile gear fishermen, 61% of mobile gear fishermen primarily identified existing developments, such as oil, gas and aggregate extraction. 56% also identified existing regulations such as quotas and licenses. Weather conditions and conflict with other fishing practices were also raised by 33% of mobile fishermen. Static fishermen primarily identified overfishing (37%) with existing developments and weather also raised by 26% of this group (Table 6.4). Existing oil, gas and aggregate extraction were raised by a greater percentage of fishermen (in relation to number interviewed in the region) as an existing issue in the Greater Wash region, compared to other regions (Figure 6.5).

Table 6.4. Existing factors influencing fishing activity and catches identified by fishermen interviews.

	Fishermen n=37	%	Mobile n=18	Static n=19
Factors other than OWF effecting activity and catches?				
Oil, gas, aggregates	16	43	11	5
Regulations	10	27	10	0
Conflict (other fishers)	9	24	6	3
Overfishing	7	19	0	7
Fish price	1	3	1	0
Fuel cost	1	3	1	0
Weather	11	30	6	5

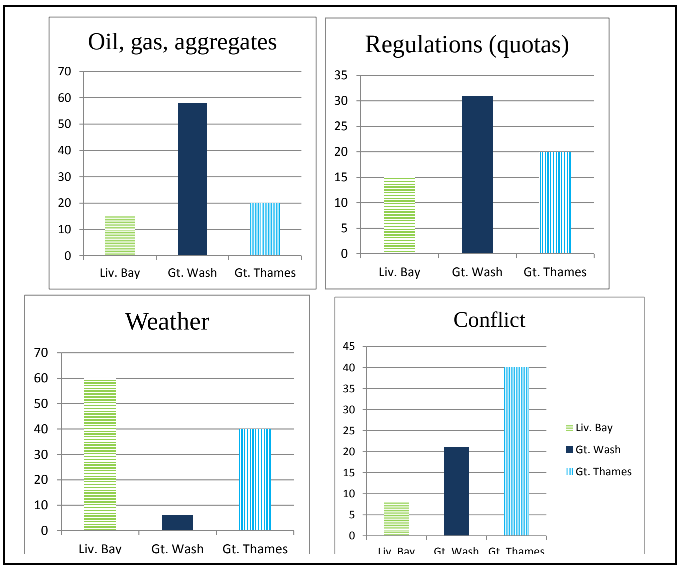


Figure 6.5 Percentage of the total number of fishermen interviewed in each region (Liv. Bay horizontal stripes, Gt. Wash solid shading, Gt. Thames vertical stripes) identifying each of the top themes in interview responses relating to existing influence on activity and catch.

Regional differences, driven by the separate existing factors effecting activity and catches in each region were also identifiable in the nMDS plot of the Bray-Curtis similarity matrix data, calculated from fishermen's responses. Interview samples from the Greater Wash were separated from those from other regions (Figure 6.6).

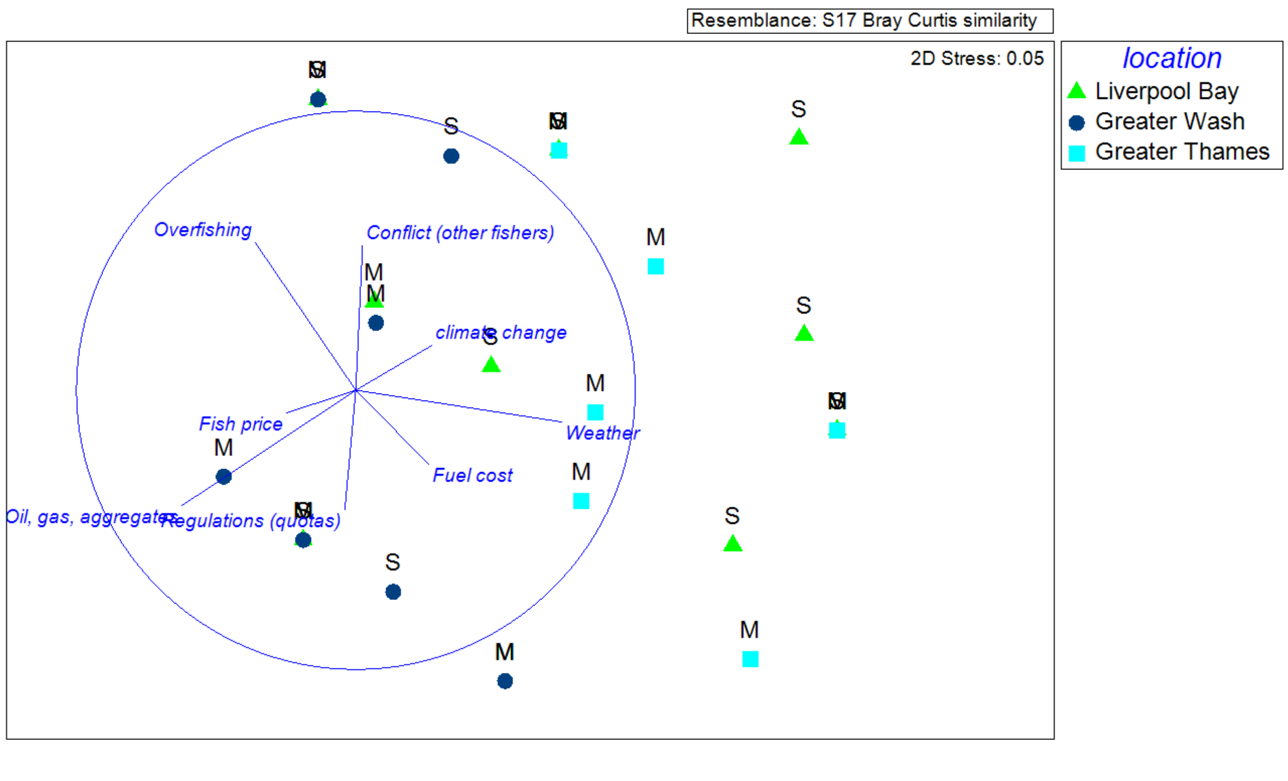


Figure 6.6 nMDS plot of Bray Curtis similarity matrix calculated from presence absence data of themes in individual interview response data from the question of existing factors influencing fishing activity and catches. Each fisherman interviewed is represented by region; Liverpool Bay (triangle), Greater Wash (circle), Greater Thames (square) and gear type used; mobile (M) or static (S). Vectors refer to the themes identified across all interviews.

Location was identified by the BV step, BEST procedure as the factor (out of fishermen's age, vessel size, gear type and location) best describing the pattern seen in responses. A very weak person correlation of 0.071 was present, suggesting a large degree of overlap between responses in each location. Observation of the original data reveals the factors: existing regulations, conflict between fishing practices and weather are mentioned by fishermen in all regions (Figure 6.6).

The SIMPER procedure displayed the coded themes contributing the highest percentage to the dissimilarity between locations were: existing oil, gas and aggregate extraction and weather between Liverpool Bay and the Greater Wash (23% and 19% contribution respectively to an overall average dissimilarity of 85%). Existing oil, gas and aggregate extraction was raised most often in the Greater Wash, and weather more often in Liverpool Bay. Between Liverpool Bay and Greater Thames weather conditions and conflict contributed highest to the dissimilarity (22% and 21.5% respectively to an overall average dissimilarity of 77.14%). Both factors were raised by a greater number of fishermen in the Greater Thames region. Between Greater Wash and the Greater Thames: oil gas, aggregates and conflict contributed greatest to dissimilarity (21% and 20% respectively) oil gas aggregate was raised more often the Greater Wash, conflict was raised more often in the Greater Thames region. There was an average dissimilarity of 85.4% between these regions.

A high average dissimilarity between mobile and static gear types of 80.6% was contributed to highest by the coded themes: existing oil gas and aggregate extraction, regulations and conflict (20.8% and 18.3% respectively). All of these themes were raised more often by fishermen operating mobile gears.

Regional differences indicated by the nMDS plot were identifiable in original data from each region. Although existing developments appeared as the factor raised most often in the combined data, the regional data displayed this was due to number of fishermen raising this issue in the Greater Wash (Figure 6.5). Comparison of inter-region data revealed 58% of fishermen in the Greater Wash region identified existing oil, gas and aggregate extraction as having an existing effect on activity and catches, whilst only 15 % of fishermen in Liverpool Bay and 20% in Greater Thames raised this theme. Within interviews this was due to existing concerns over the effects of suspended sediment on declines in cockle and mussel harvests (from aggregate dredging and dredging for beach replenishment). The different nature of fisheries in this region, targeting different species to other regions may have influenced importance of this issue within the region. Some issues such as fuel cost did not receive as much attention as may be expected. If prompted, fishermen would often add this, but it was possibly only mentioned as an aftermath as the focus of the interview was on regional issues.

6.3.6 Changes in occurrence of species (Objective 3)

Changes in abundance of specific species in relation to OWF sites provided mixed responses. Catches of commercial species were identified to have decreased. Although, 19% of respondents, primarily in the Greater Wash and Liverpool Bay regions did acknowledge increases in juvenile cod family (Gadidae) species and crustaceans. Increases in commercial species were expected within turbine safety zones (crustaceans), or for juvenile fish (cod and whiting). Greatest increased abundance had been observed for non-commercial species such as common starfish (*Asterias rubens*), or species that could not be harvested due to occurring within turbine safety zones. These included brown crab (*Cancer pagarus*), European lobster (*Homarus gammarus)* and seed mussel (*Mytilus sp*.) (Table 6.2b).

6.3.7 Initial fishing industry perceptions coming to light (Objective 4)

Comparison of the experiences of fishermen in 2011 with 2006 (Mackinson et al. 2006) revealed certain perceived issues in 2006 were identified as occurring in 2011. As information required by questions in this section repeated information discussed earlier in the interview, approximately 10 interviewed fishermen asked to skip these questions. It is important to consider that even in 2011, few of the larger round two sites had been completed or even begun construction and round three sites had only recently been announced (Figures 4.1a, 5.1, 5.2, 5.3). The perceptions stated in 2006 were in relation to these larger sites and in

2011 many factors remained unchanged. Experiences recorded in 2011 may change once the larger sites are under construction and operational. Future surveys, once larger developments are completed, would provide useful comparative data sets, especially if issues are mitigated in the mean-time.

In line with early perceptions (collected by Mackinson et al. 2006) the catch of principal targeted species had been experienced to decline post OWF construction, as had income from fishing. Likewise few employment opportunities had arisen from using vessels for OWF supply and survey work, as had been identified as an issue in 2006. Running costs had also been experienced to increase, as perceived in 2006, with increased fuel costs and purchase of more powerful engines required to increase range and travel time (Table 6.5).

Reduced catches were reported in relation to OWF development by both mobile (71%) and static gear fishermen (70%) that answered this set of questions (n=27). This lower sample size, especially for static gear fishermen (n=10), is important to consider in results, as views of all active fishermen in the region are not provided. Results suggested economic impacts had been greater for mobile fishermen, 76% of mobile fishermen experienced decreased income compared to 50% of static gear fishermen. Increased effort in remaining grounds and associated effects, such as, increased competition and decreased resources were reported by both of mobile gear fishermen (65%) and static gear fishermen (60%). Remaining fishermen suggested no change, as OWFs had not yet been constructed on the preferred grounds they fished (e.g. fishermen using cockle grounds within the Wash estuary or inshore crab fishermen using beach launched boats in North Norfolk).

Lack of additional income opportunities from using fishing vessels for OWF related work were common across all gear types and locations, as were increased running and equipment purchase costs. Decreased time spent fishing per trip had been perceived in 2006 to be a direct outcome from OWF development. However, in 2011 the majority of respondents related that time fishing had remain unchanged. This was discussed in the context of existing limitations on the time available to fish, due to range of vessels, constraints on having to return to tidal harbours on mid to high tides (as no access at low tide) and customer expectations for angling charters. In other instances reduced fishing time had been mitigated where possible with purchase of more powerful engines or increased effort in remaining fishing grounds (Table 6.5).

Table 6.5 Fishermen's experiences in 2011 in relation to the issues identified in 2006 by Mackinson et al. (2006)

	Fishermen n=27	%	Mobile n=17	Static n=10		Fishermen n=27	%	Mobile n=17	Static n=10
Specific effects: species abundance					*Effort in remaining grounds*				
increase	11	41	8	3	increase	17	65	11	6
no change	9	33	6	3	no change	8	31	4	4
decrease	7	30	3	4	decrease	1	4	1	0
Distance travelled					*Use of boat for other work*				
increase	11	41	6	5	increase	3	11	2	0
no change	15	56	10	5	no change	22	81	14	8
decrease	1	4	1	0	decrease	2	7	0	2
Catches of target species					*Income from fishing*				
increase	1	4	0	1	increase	0		0	0
no change	7	26	5	2	no change	9	35	4	5
decrease	19	70	12	7	decrease	17	65	13	5
Time spent fishing on trip					*Gear purchase and vessel costs*				
increase	3	12	2	1	increase	11	41	5	6
no change	18	72	11	7	no change	16	60	12	4
decrease	5	20	3	2	decrease	0	0	0	0

6.3.8 Management and Mitigation requirements (Objective 5)

Divisions were apparent between responses of static and mobile fishermen on the best planning solution to accommodate MPA networks, OWFs and fishing. Mobile fishermen primarily identified better consultation (44%), mitigation of the negative effects of pile driving, noise and potentially EMF as a priority before any planning solution (28%) as well as the perception that there was no planning solution (28%). Mobile fishermen also indicated co-location would present a viable planning option (22%). However, mobile gear fishermen identified the benefit from co-location came from avoiding greater loss of fishing grounds from MPAs being designated in remaining grounds.

Static fishermen raised co-location of MPAs as a planning solution by a larger percentage than mobile fishermen (32% of static fishermen), with the caveat that static gear fishing was allowed in the MPA. Deploying artificial reefs within OWFs, or maximising opportunities for reef deployment as scour protection was also consistently raised by static gear fishermen (Table 6.6). Similar priorities for potential solutions were identified across study sites (co-location, limiting effects of disturbance and better consultation), if the small sample size in the Greater Thames region is taken into account (Figure 6.7). MPA co-location and deploying of artificial reefs were suggested more often in interviews in Liverpool Bay. This was, in part, due to charter angling vessel operators identifying potential benefits to reef fishing.

Table 6.6 Themes emerging from fishermen's responses to the question: 'What in your view is the best planning solution to accommodate fishing, OWFs and MCZs?'

	Fishermen n=37	%	Mobile n=18	Static n=19
Best solution to aid planning?				
Consultation	11	30	8	3
MPA Co-location	10	27	4	6
No solution	8	22	5	3
Address piling & EMF	7	19	5	2
Artificial reefs	6	16	1	5
Aid Access	1	3	0	1

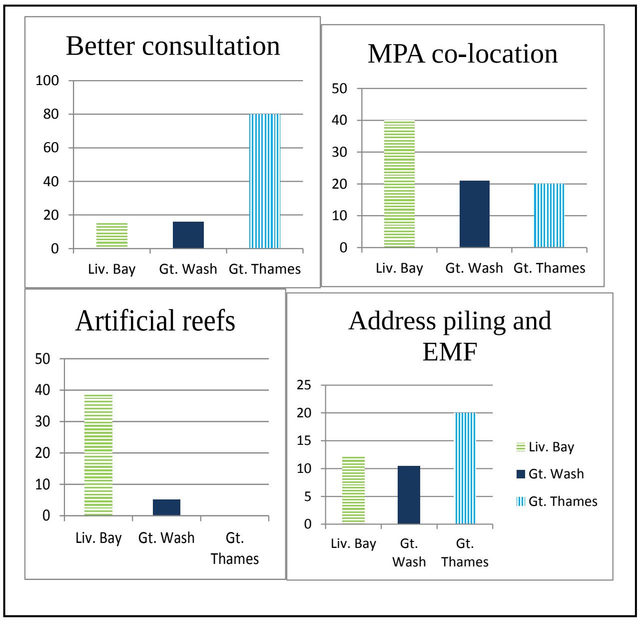


Figure 6.7 Percentage of fishermen within each region (Liv. Bay horizontal stripes, Gt. Wash solid shading, Gt. Thames vertical stripes) identifying each of the top themes in interview responses relating to: 'What is the best planning solution to accommodate fishing, OWFs and MCZs?'

The nMDS plot of the Bray Curtis similarity matrix of individual fishermen's responses on the best planning solution to balance activities reflects the similar priorities identified across regions (Figure 6.8). Separation between mobile and static gear types however, was evident in this analysis. The vectors for the themes 'deploy artificial reef and co-locate MPA' show a small interrelationship in interviews with static fishermen in Liverpool Bay and Gt. Wash regions. Maintaining access and mitigating piling noise appeared interrelated in interviews with mobile gear fishermen in Gt. Wash and Gt. Thames regions (Figure 6.8).

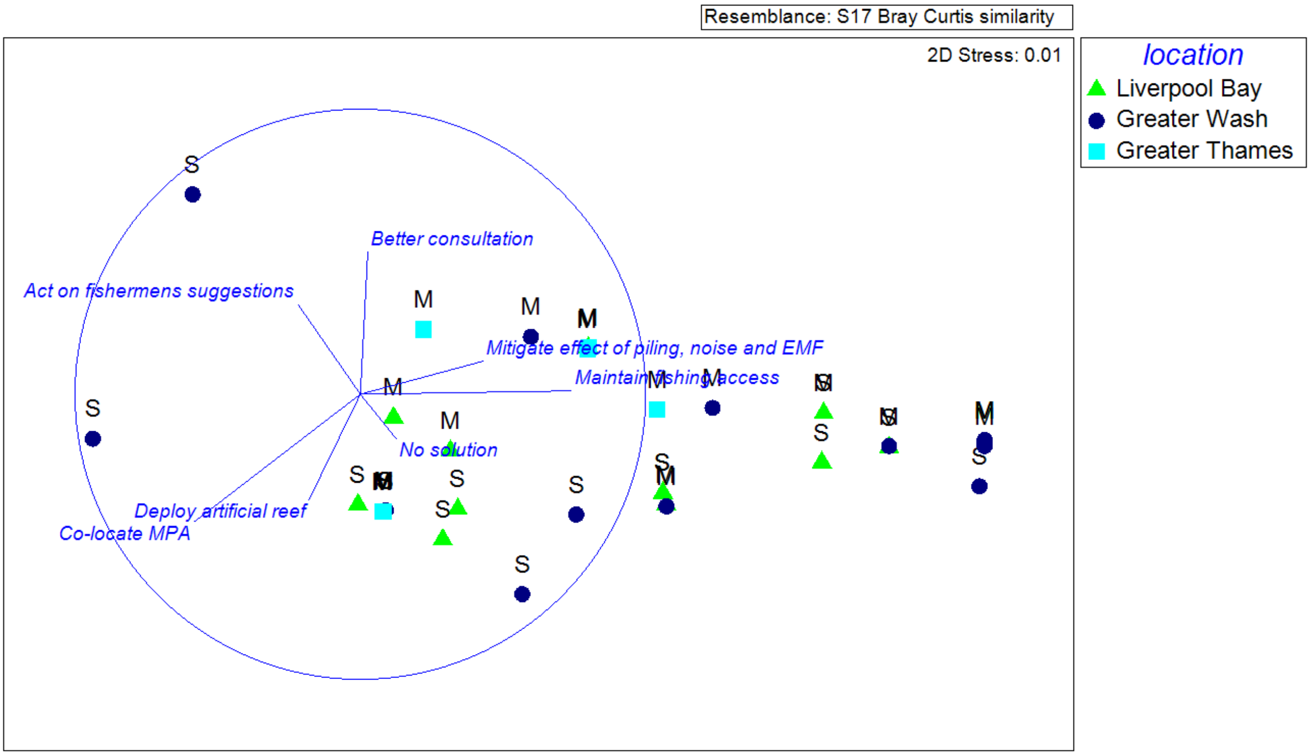


Figure 6.8 nMDS plot of Bray Curtis similarity matrix calculated from presence absence data of themes in individual interview response data from the question of planning solutions to enable activities to co-exist. Each fisherman interviewed is represented by region; Liverpool Bay (triangle), Greater Wash (circle), Greater Thames (square) and gear type used; mobile (M) or static (S). Vectors refer to the themes identified across all interviews.

The BV step BEST procedure revealed 'gear type' best described the distribution in interview responses although with a very weak person correlation of 0.06. The SIMPER procedure identified a high dissimilarity between mobile and static gear fishermen's responses (85%). The principal themes responsible for the high dissimilarity were the greater number of static gear fishermen raising co-location of MPAs allowing static gear fishing only in OWF (contribution of 22.8%) as a solution, and the greater number of mobile fishermen identifying a need for better consultation (contribution of 16.6%). Mobile gear fishermen identified improved consultation was required at the earliest opportunity in the planning phase, to avoid locating OWFs on fishing grounds or maintain access within the design of OWF arrays.

6.4 Summary of results

Development of OWFs across three UK regions has affected fishing activity and catches with a greater identifiable impact on fishermen utilising mobile gears. In this study, I examined the experiences and perceptions of changes in fishing activity and catches of commercial fishermen and angling charter vessel operators in three UK OWF development areas. Respondents also provided views on the best planning solution to allow fishing, renewable energy development and the designation of an effective MPA network to co-exist. The results indicate that experiences in relation to the effects of OWFs on fishing activity and catches, and potential planning solutions identified differ according to the OWF development area and gear type used by the fishermen. Certain existing pressures were similar across areas (weather, regulations, conflict between gear types), but a small number of region specific issues were apparent (e.g. Suspended sediment in Gt. Wash). Fishing practices and species targeted in a region are likely to have led to greater identification of specific regional issues (e.g. fisheries targeting species sensitive to increased suspended sediment in Gt. Wash). Results are summarised in Table 6.7.

Table 6.7 Summary of findings from fishermen interviews including a review of confidence in findings and benefits and limitations of the methods and data provided.

Objective	Findings	Summary	Confidence	Benefits	Limitations
Backgound situation	▪Weather, fish behaviour and each fishermen's knowledge of regional grounds were given as reasons for choosing the grounds fished in all regions. ▪Catches had declined over recent years across all regions, environmental changes, overfishing, offshore developments, aggregate extraction and reduced quota were identified as reasons for this.	▪ Similar reasons were provided in each region for why fishermen chose the grounds fished. ▪ Reduced quota, overfishing and environmental changes were identified in all regions as affecting fishing. ▪ Aggregate extraction and dredging of sand for beach replenishment were identified by more fishemrnen in the Greater Wash region.	▪ High (reasons for choosing where to fish). ▪ Moderate (what has affected fishing over the last 10 years)	▪ Interviews provided opportunity for fishermen to provide insight into the factors affecting fishing.	▪ Small sample size compared to the total number of fishermen active in the UK, therefore, many further issues, or ability to identify the most important facors nationally, relating to changes in fishing activty over the past 10 years may be missed. ▪ Small sample size in the Greater Thames limits interpretation for this region.
Objective 1 -2: 1. Effects of OWF development on fishing activity and catches. 2. OWF related factors perceived to influence activity and catches.	▪ Increased percentage of fishermen using mobile gear identified that OWFs had affected fishing activity and catches (compared to percentage using static gear). ▪ Lost ground and pile driving noise were identified as negative effects across all gear types and locations. ▪ Potential for EMF to be effecting catches was raised by greater numbers of static (angling charter) fishermen in Liv. Bay. ▪ Negative effects of siltation were identified, primarily by mobile and static gear fishermen in the Gt. Wash region.	▪ Differences in responses between study regions and fishing practices were observed. ▪ Potential for effects from EMF were raised, principally by angling charter boat operators in Liv. Bay who had observed elasmobranchs were no longer caught at marks near the OWF, but were now more common in shallower regions inshore. ▪ Otter trawl fishermen had noticed large declines in flatfish in Liv. Bay and also raised potential of EMF as a cause. ▪ Burying of cockle beds, failure of mussel beds, and parlour pots and drift nets containing increased sediment and loose seaweeds were related to OWF construction activity (increasing suspended sediement and debris) by fishermen in Gt. Wash and Gt. Thames regions.	▪ Moderate	▪ Responses on a 5 point scale provided comparable data. ▪ Fishermen responses provide information on daily observation of changes since OWF development.	▪ Questions lead about OWF effects, therefore, political and economic issues such as compensation may influence responses. ▪ Issues such as EMF have not been thoroughly proved to effect elasmobranchs in field studies. The observations of fishemrne are valuable insights, identifying a need to investiagte patterns further. Concerns across the industry over OWF development and associated press may influence responses. ▪ Negative effects from increased suspended sediment and debris require investigation. This issue was identified in a region with existing concerns over aggregate dredging and beach replenishment. Effects of these activities need to be seperated from OWF construction to understand impact.
Objective 2: Existing factors influencing fishing activity and catches.	▪ Existing developments and aggregate extraction, regulations, conflict between fishing practices and weather were the most often raised existing factors. ▪ Similar factors were raised across each region, although a higher number of fishermen interviewed in the Gt. Wash raised aggregate extraction than in other regions.	▪ Large degree of overlap between repsonses in regions suggests certain issues across the fishing industry in 2011. ▪ Views of negative effects of exitisting aggregate extraction were prevalent in Gt. Wash interviews, suggesting a region specific issue, linked to fishing practices in the region (species sensitive to increased suspended sediment). ▪ The pre-existince of issues is likely to influence perceptions of the effects of OWFs. Or OWF development may magnify existing issues. ▪ Suggets a need to address effects of OWFs on resource users on a region specific basis, paying atention to existing issues and effects on each fishing practice.	▪ Moderate	▪ Fishermen responses provide information on daily observation of changes since OWF development.	▪ Interviews with fishermen outside of developemnt regions would have aided comparison. ▪ Small sample size in the Gt. Thames limited input from this region and over-emphasised contribution of individual fishermen's repsonses to region. ▪ Issues of current regional concern (such as suspended sediment from dredging in Gt. Wash) may limit identification of further issues in the region.

Objective	Findings	Summary	Confidence	Benefits	Limitations
Objective 3: Changes in occurrence of species.	▪ Catches of commercial species were observed to decrease. ▪ The largest species specific increase was for common starfish (*Asterius reubens*). ▪ Increases were also suggeted in abundance of crab (*Cancer pagarus*) and lobster (*Homarus gammarus*), as well as juvenile whiting (*Merlangius merlangus*) and cod (*Gadus morhua*). ▪ Decreases were noted for elasmobranchs and flatfish	▪ Increases (potential) were noted for commercial species (crab and lobster) but benefits were not seen by fishermen as they could not fish close to turbines, due to safety restrictions, or risked gear becoming entangled with pilings. ▪ Decreases for elasmobranch and flatfish catches were identified in Liv. Bay. Distribution of elasmobranch species targeted by angling charter operators had changed. Flatfish catches, reported by a small sample of otter beam trawl fishermen, had decreased in this region. 2 respondents in the Gt. Thames also suggested a decrease in flatfish catches.	▪ Moderate	▪ Fishermen responses provide information on daily observation of changes since OWF development.	▪ Issues such as compensation payments from OWF developers may influence responses, or willignness to fish in proximity to OWFs to trial for catches of commercial species. ▪ Small sample sizes in the Gt. Thames, where demersal netting and trawling takes place and small numbers of active demersal trawl fishermen remaining in Liverpool Bay limited confidence in identification of changes in catches of specific species (relating to these fisheries).
Objective 5: Management and mitigation solutions: 'Best planning solution to accommodate fishing, OWFs and MCZs?’	▪ A need for improved consultation was raised by interviewed fishermen. ▪ Benefits from MPA co-location were identfiied by both mobile and static fishermen. ▪ A need to address piling noise and potentially EMF were also identified.	▪ Consultation was required from the earliest planning and development stage. ▪ Fishermen considered that if developers and planners took action on their (fishermens) views on OWF placmeent to avoid important fishing grounds then the need for later mitigation would be avoided. ▪ Static fishermen viewed co-location as beneficial if mobile activity was banned but nets and pots were allowed. ▪ Mobile fishermen identified co-location as beneficial if it meant loss of grounds to MPAs would be avoided elsewhere.	▪ Moderate	▪ Fishermen responses provide information on daily observation of changes since OWF development.	▪ This question, as well as the project title and introduction to the interview discussed MCZs (MPAs) which may have lead interviewed fishermen to focus on this topic. ▪ Small sample size compared to the total number of fishermen active in the UK, therefore, many further issues, or ability to identify the most important factors nationally, relating to planning solutions may be missed. ▪ Small sample size in Greater Thames limits interpretation for this region.

6.5 Discussion

6.5.1 Value of existing knowledge

Consistent responses across all regions and gear types were provided in relation to the main reasons fishermen fished the grounds they chose. The importance of fishermen's knowledge of fishing grounds, built up through years of experience at sea and also passed down through generations within a region was identified by every respondent. This knowledge of the fishery and experience of changes in distribution and catches of species, has received increasing attention as a valuable resource, to understand trends in ecology and inform ecological and economically sustainable management (Johannes et al. 2000; Hind 2012). Need for greater attention to fishermen's ecological knowledge has been identified in respect to fisheries that have subsequently collapsed through poor management (Neis et al. 1999), and to design of successful MPAs (Surronnen et al. 2010; des Clers 2010).

Interviews conducted in this study often identified knowledge of fishing grounds and therefore the economic success of fishing trips were based on experience, and even multi-generation knowledge. The possibility of having to find and learn new grounds was discussed as presenting economic challenges in many instances. This was especially relevant where displacement from grounds had occurred. Displacement effects were identified related to safety and vessel running costs from exploiting new, often distant grounds, reflecting concerns in 2006 (Mackinson et al. 2006). Building up effective knowledge provides a significant economic resource within a fishermen's business (Hutton et al. 2004; Anderson et al. 2012). The cost of searching for new grounds and learning the dynamics of new areas is likely to negatively affect fishermen in OWF development regions (Sanchirico et al. 2002). A range of ecological, economic and social concerns from increasing activity in remaining grounds were identified in interviews. These include increased conflict as mobile and static gear fishermen compete on the same grounds. For instance, in the Greater Wash static gear fishermen discussed mobile gear vessels towing through a string of pots and the expense of replacing that equipment (likewise mobile gear fishermen discussed being unable to fish grounds due to the presence of static fishing equipment). In Liverpool Bay charter boat anglers discussed the need to conduct longer trips to satisfy customers, reducing time and increasing stress on families.

6.5.2 Changes in activity and catch – ecological and economic consequences (Objectives 1-3)

Changes in fishing activity were reported by fishermen following OWF development in each region. The further ecological effects of displaced fishing effort and knock on economic effects on long term sustainability of regional fisheries are important to consider. Changes in fishing activity and catches were reported to be greater for mobile gear fishermen. Mobile gears such as beam trawls are also understood to have greater impact on benthic ecology (Dinmore et al. 2003; Kaiser et al. 2006). Following the 2001 cod box closure in the North Sea, Dinmore et al. (2003) utilised international beam trawl VMS data to quantify spatial activity for over 15 metre beam trawl vessels. After the area closure fishing effort increased in remaining areas and also moved into previously un-fished areas. Modelling of the recovery of previously un-impacted benthic communities from the effects of displaced beam trawling suggested recovery could take up to 10 years for large hard-bodied macro-benthic organisms (Dinmore et al. 2003). Rjisdorp et al. (1998) also reported similar effects following the closure of the plaice box in the southern North Sea.

Increased competition in remaining grounds is likely to have not only ecological impacts, but reduce catches and economic return for fishermen (Rjinsdorp et al. 2000). In an economic impact assessment of proposed marine conservation zones in the Irish Sea, Cappell et al. (2012) displayed potential long term economic impacts on the inshore Nephrops fleets working from northern Irish ports. The loss of the fishery to these ports was also predicted to affect unemployment in the region. At the time of the report 6% of employment was related to the Nephrops fishery and related processing industries. With fishing activity by inshore vessels in the UK significantly decreasing in recent years, fewer active vessels are present to support sea and shore-based employment (Curtis and Barr 2012; Anderson et al. 2013). Understanding the cumulative ecological and economic effects of fishing activity changes from OWF developments, existing activities and proposed MPA closures is therefore of importance for marine and shore-based economic impact assessments.

6.5.3 Cumulative effect – including other pressures and activities (Objectives 1-3)

Interviews highlighted the fact that effects from OWF development have occurred amidst a number of other pressures which have affected the fishing industry in the UK. Catches had been experienced to decline by most fishermen over the last ten years, suffering impacts from existing oil, gas and aggregate extraction, management regulations and conflicts between fishing practices, as well as broader scale environmental changes. The presence of existing pressures highlights the need to appreciate the cumulative impact on traditional resource users such as fishermen from new developments in relation to all existing pressures. Berkenhagen et al. (2010) acknowledge the cumulative impacts of multiple OWF developments on fishermen from associated loss of fishing ground, and therefore fishing opportunities. Less research appears to have been carried out on cumulative impacts of multiple OWFs in addition to existing pressures and future developments such as MPA networks. This highlights the importance of considering co-location of activities and the role of marine spatial planning in resolving issues (Christie et al. 2013).

Cumulative impact assessment on the marine environment has received attention (Foden et al. 2010; OSPAR, 2009; ICES, 2013) but little work is apparent in relation to economic impacts on fisheries from multiple marine activities. On an individual basis the other existing factors affecting fisheries identified in interviews have received attention. The effect of climate change on fisheries (Roessig et al. 2004; Worm et al. 2006; Allison et al. 2008), the effect of regulations and management (Wilen 2000; Daw and Gray 2005), effects of oil rigs (Lokkeborg et al. 2002; Soldal et al. 2002; Cripps and Aabel 2002), gas rigs (Chesney et al. 2000; Fabi et al. 2004; Scarcella et al. 2011), aggregate extraction (Stelzenmuller et al. 2010), conflict (Salas and Gaertner 2004), and overfishing (Jackson et al. 2001; Hilborn et al. 2003), have all been approached from a number of angles in current research.

Drawing this knowledge into environmental, economic and social impact assessments for marine spatial plans has begun in the UK under MSP related to the MCAA 2009 (HM Government 2011; MMO 2013b). Developing frameworks and best practice for understanding cumulative environmental, economic and social effects and impacts is recognised as a vital area within MSP (HM Government 2011; MMO 2013b, 2013d). Across Europe the need for frameworks and best practice for cumulative assessment have been addressed by ICES and OSPAR for the North-East Atlantic region. Frameworks and research focus on identifying trends of increasing or decreasing impacts within regions and effects on the goal of achieving *Good Environmental Status* (GES) by 2020 (under the European Marine Strategy Framework Directive (2008/56/EC)) (OSPAR, 2009). ICES (2013) have also addressed anthropogenic pressures and their cumulative effects on the state of the marine environment. The decision support tools under development enable quantification of required reductions of multiple pressures (to meet GES) (ICES 2013). These decision support tools and frameworks focus on maintaining or restoring ecosystems. As healthy ecosystems will benefit sustainable fisheries, understanding impacts of OWFs and other pressures on ecosystems and managing trends will limit long term impacts on resource users. Adaptive management is being applied within marine planning in the UK and Europe that will monitor environmental, economic and social effects of plans, and adapt plans to reduce impacts within planning regions (HELCOM/VASAB, OSPAR, ICES, 2011; MMO 2013b).

Interviews responses suggested the development of OWFs added to existing pressures on fisheries in each region. Due to the different existing activities present in each region, the interactions and pressures were different on a region by region basis. This was evident in relation to aggregate extraction and associated effects such as sedimentation. There was far greater focus on this topic in the Greater Wash region where extensive beach replenishment and aggregate extraction were common (DeGroot 1979; Desprez 2000; Gubby 2003). In the remaining two regions sedimentation, particularly suspended sediment and debris (loose seaweed) during construction was acknowledged, but less consistently than other effects such as construction noise and loss of fishing grounds.

The nature of the fishery in each region is equally important in understanding pressures. In the Greater Wash there was limited demersal trawling and netting for species such as cod and plaice. All Wash fisheries principally targeted bivalves, which display low tolerance from increased sedimentation (e.g. cockles, mussels, Ellis et al. 2002). Crustaceans targeted in the wider region are likely to move away from areas experiencing increased sediment covering (e.g. brown crab, Shelton 1973), or suffer stress from increased noise pollution (e.g. brown shrimp, Lagardere 1982). The traditional conflict resolution between mobile dredges and shrimp beam trawling vessels working from Wash ports, and the potting fisheries operating from North Norfolk coastal ports was also put under pressure in this region. Spatial pressure from lost seed mussel fishing grounds was identified by respondents to have led to mussel dredge activity occurring on traditional potting grounds, leading to increased tension.

6.5.4 Loss of ground - increase in pressure (Objectives 1-3)

Loss of fishing grounds from OWF development has been discussed as the principal issue identified by both mobile and static fishermen. The greatest impact was identified by the majority of mobile fishermen. This supports the findings from analysis of spatial fishing activity data sets before and after OWF construction (Chapter 5). As the spatial scale of OWF development increases, and moves on to more active fishing grounds it is reasonable to expect that pressures on fisheries will increase. The ecological effects of OWFs, identified in chapters 4 and 5 also display potential species benefits for target species for static gear fisheries such as crab and lobster, but limited benefit for species targeted by mobile gear fisheries, plaice and sole in particular.

Evidence for increased commercial species abundance exists from OWFs in other European states (Stenberg et al. 2011; Reubens et al. 2010, 2013; Bergstrom et al. 2012). In these cases benefits to fish and crustacean abundance relate to the presence of scour protection. Scour protection has only been deployed for two of the eleven early UK OWFs (Ottensen - Hansen 2005; DECC 2008). However, as developments move into deeper waters they are increasingly utilising rock and boulder armouring and scour protection (DECC 2008). Whilst larger, future developments, stand to increase spatial pressure on fishing activity, they provide greater potential to aid abundance of target species if scour protection is deployed (Punt et al. 2009; Wilson and Elliott 2009; Christie et al. 2013). It is also important to consider that fish species targeted by mobile fishing techniques, such as cod have been shown to be sensitive to anthropogenic noise, especially at the levels created by pile driving (Thomsen et al. 2006). There is also evidence of the sensitivity of elasmobranchs to electrical disturbance from live cables and sensitivity of commercially targeted flatfish species to magnetic disturbance (Gill et al. 2009; Metcalfe et al. 1993, 2006; Bentley et al. 2012). Less evidence exists on the impact of species targeted by static gear such as crab and lobster to noise and EMF, although this area is a priority for further investigation (Everitt 2011, Woodruff et al. 2011).

Knowledge is required on these potential negative effects on species and the required mitigation needs to be identified and put in place. Potential benefits exist to species abundance from habitat creation, combined with the reduction of fishing activity within OWFs. Measures to maximise these benefits need to be developed alongside mitigation to address any negative effects discovered. Fishermens perceptions of benefits from OWFs may be more positive once developments have become established, if thorough early consultation and appropriate mitigation are put into practice (Sweeting and Polunin 2005; Jones 2011).

6.5.5 Perceptions to experiences (Objective 4)

Comparison between fishermen's perceptions in 2006 and experiences in 2011 revealed not all perceived effects have materialised. However, the perceived effects relevant to the scale of the round one OWFs present in 2011 were reported in fishermen's experiences. Decreases in catches, income from fishing and limited employment opportunities utilising fishermen's vessels had occurred, as suggested in responses in 2006. Decreases in catches and income and increased effort displacement were raised by a greater number of mobile fishermen in 2006 and this was also seen in this study (Table 6.8).

Even at the time of Mackinson et al.'s 2006 study the questions were designed to initiate responses in relation to the scale of planned round two OWF (typically 100 turbine OWFs, in contrast to the smaller, 30 turbine round one OWFs). Consistency of fishermen's perceptions identified by Mackinson et al. (2006) with current experiences suggests the perceptions identified in 2006 in relation to the larger round two and three OWFs will be highly relevant.

Therefore, it is of importance to further establish evidence of effects, and develop mitigation and associated marine planning resolutions at the earliest opportunity.

Table 6.8 Comparison of identified issues in 2006 (Mackinson et al. 2006) to fishermens experiences in 2011.

Objective	Issue/outcome identified/predicted in Mackinson et al., 2006	Outcome in 2011 (% of total fishermen answering relevant interview question) Increase	No change	Decrease	Summary	Limitations
Objective 4: Identify through interviews in 2011 if issues and outcomes from OWF development perceived in surveys conducted by Mackinson et al. (2006) have come to pass.	▪Increased time steaming instead of fishing.	41	56	4	▪ As right of passage was possible through existing OWFs in 2011 only fishermen who had lost grounds or identified a need to avoid OWF in rough weather suggested there had been an increase.	▪These questions were at the end of the interview and approx 10 fishermen saw providing this information as repeating what had already been provided, so asked to skip these questions (limiting the sample). ▪Sample sizes were small in the Gt. Thames reducing the input from this region. ▪Fishermen interviewed mainly operated smaller day boats (under 10m).
	▪Reduced catch.	4	26	70	▪ The majority of mobile static fishermen answering this question identified reduced catches (reasons are explored in Table 6.3).	▪As above
	▪Greater effort on remaining grounds.	65	31	4	▪ Only one otter trawl fisherman and angling charter operators in Liv. Bay discussed fishing within OWFs and reported no benefit to catches. Fishermen reported increasing effort in remaining grounds if they had lost grounds within an OWF. Fishermen reporting no change had generally not lost grounds to OWF development (such as beach launched crab potting vessels in North Norfolk, Gt. Wash).	▪As above
	▪Little wind farm work around.	11	81	7	▪ Fishermen reported little opportunity for OWF work in 2011, many added that they preferred to fish rather than provide supply boat or guard boat work. The preference for specifically designed vessels for supply work (catamarans with comfortable facilities) was also mentioned as limiting opportunities for local boats. One over 10m trawler fisherman used the vessel for guard boat work and mentioned it helped him provide a year round wage for his crew, especially when quotas would have meant they would otherwise have not been earning year round.	▪As above, in particular that fishermen interviewed were mainly operating smaller day boats (under 10m), which would be less suitable for offshore guard boat work.
	▪Income from fishing (issue: Loss of profit)	0	35	65	▪ Responses reflected the reduction in catches and changes to fishing activity. ▪ Charter vessel operators also mentioned their customers would not return if catches were bad or it took too long to travel to fishing marks.	▪As above, also: ▪ Compensation payed for lost fishing opportunities may influence reponses.
	▪Increased costs	41	59	0	▪ This was related to steaming time in most fishermen's responses. ▪2 angling charter vessel operators also mentioned buying and installing new larger engines to get customers fishing marks within a days fishing trip.	▪As above
	▪Increase in general marine species	41	33	26	▪ Largest increases had been seen in star fish, particularly *Asterius reubens* in Gt. Thames OWFs. ▪ Increases in crustacean (crab and lobster) were raised if OWFs contained rock armouring. ▪ Angling charter vessels reported juvenile whiting being abundant in a Liv. Bay OWF.	▪As above

6.5.6 The best planning solution (Objective 5)

Fishing practice (gear type used), grouped as mobile or static was an important factor separating interview responses on the best planning approach, to allow co-existence of fishing, OWFs and MPA networks. The regional disparity which had existed in relation to effects of OWFs and in relation to existing pressures was less present in these responses. Fishermen shared responses which provided opportunity for them to continue their economic activity. There was also strong appreciation of the need for sustainability.

The different effect of OWFs on mobile and static fishing activity and landings was apparent in responses, especially in the identification of benefits from co-location. Fishermen utilising static gear identified direct benefits if mobile vessel activity was not permitted in proximity to OWFs. Static fishermen also suggested additional benefits if habitat augmentation was deployed, such as artificial reefs, and fishing activity was allowed within current safety zones around monopiles (where catches were perceived to be highest). Fishermen utilising mobile gears identified a need for better consultation and planning of future OWFs. The only direct practical benefit of co-location suggested by mobile fishermen was it would limit cumulative loss of fishing grounds.

The need for better consultation was identified to avoid conflict from locating OWFs on lucrative fishing grounds and to resolve issues before the construction phase. The issue of consultation has repeatedly appeared since the earliest OWF developments (Gray et al. 2005; Mackinson et al. 2006; Blyth Skyrme 2010, 2010a; Rodwell et al. 2012, 2013; Alexander et al. 2013). The generic feeling amongst fishing communities present in early studies has been that fishermen do not have a strong voice in negotiations (Gray et al. 2005). Consultation was identified as having been started too late during surveys with fishermen in 2006 (Mackinson et al. 2006). The need for early consultation with fishermen at the planning stages of developments was further established in discussion between fishing industry and renewables industry personnel in 2009-2010 (Blyth Skyrme et al. 2010). However, according to interview responses in 2011, these suggestions appear to have not been put into practice. Mitigation options are further addressed below and summarised in Table 5.7.

i) Improving communication and consultation

The lack of progress on resolving consultation practice issues may be responsible for the negativity present in many fishermen's responses to this interview question. Responses such as '*there is no solution*' and '*they'll do what they want anyway so what's the point'* were raised by a number of respondents, particularly mobile fishermen. The practical challenges of utilising bottom towed fishing gear within OWFs were raised by mobile gear fishermen as leading to reluctance to fish in proximity to OWF sites. Uncertainty over the liability and protocol if fishing gear entangles OWF infrastructure were present in responses, as were concerns over safety risks if gear snags OWF infrastructure. Although safety zones (~50m exist around each turbine) strong tides and adverse weather were raised as risks preventing these being effective when towing demersal trawls within an OWF. This raised risks of capsizing vessels in the event of towed fishing gear snagging and risk of collision. Lack of clear information on what debris or infrastructure may be on the sea bed caused concern. It was discussed that if a trawl snagged, even outside a safety zone, a vessel could be at risk of collision. These concerns limited optimism from mobile gear fishermen for effective mitigation. Co-location of MPAs with OWFs was raised by many mobile gear respondents as being beneficial, in the context that this would reduce grounds lost or closed to fishing outside OWF development zones. The opportunity to reduce the total grounds lost was identified by mobile fishermen above the potential for species augmentation.

Many of the issues and potential mitigation solutions raised in this study repeat the issues and relevant solutions previously discussed in existing fishermen survey exercises and workshops (Mackinson et al. 2006; Blyth Skyrme 2010, 2010a). Following this study, the reasons why previously identified mitigation issues and solutions have not been addressed were approached in a national workshop (Rodwell et al. 2013, deGroot et al. 2014). Case studies where successful consultation and mitigation had occurred were identified in the Greater Thames region (Rodwell et al. 2013). Both fishing industry representatives and renewable industry representatives identified a consistent representative was required from each industry to act as a spokesperson for negotiations. Negotiations should be initiated at the earliest possible opportunity in the planning stages and clear actions identified and agreements recorded in legal documents in a business to business manner (Rodwell et al. 2013). Open access information sources in the fishing industry such as '*Kingfisher'* were identified to be able to provide news and updates on access to grounds and permitted gears for OWF sites as well as chart updates for new navigational hazards (Rodwell et al. 2013).

ii) Account for cumulative impacts from activities

The addition of OWF development, on top of a number of existing spatial conflict and regulations restricting fishing activity, was viewed as having a greater impact on the smaller vessels in local fleets. Impacts were escalated for this sector by specific current and historical issues. These included existing regulations limiting effort and quantity of landings (Wilen 2000; Daw and Gray 2005), impacts from existing extractive activities such as oil, gas and aggregate extraction (Rogers and Stocks 2001) as well as historical and existing conflict from other fishing activities, particularly larger mobile gear fishing vessels from across Europe (Pengelly 1979; Crean 2001). If benefits to presence and abundance of commercial species targeted by mobile gear fisheries continued to be limited, interviewed fishermen operating inshore vessels in this sector viewed OWF development as '*the final nail in the coffin*.' Larger vessels however have the range to avoid inshore OWFs, as identified in a similar case study in Lyme Bay (Mangi et al. 2011). However, respondents operating larger vessels using mobile gears still raised this issue in respect to the planned large OWF developments further offshore.

iii) Mitigation requirements

Potential benefits to species abundance were discussed by mobile gear fishermen as well as static gear fishermen. Fishing using towed gear in proximity to OWFs was claimed to have returned little benefit. As a result fishermen identified a need to investigate the effects of disturbance of sediment, noise, and EMF on fish abundance to understand if these factors were responsible for lack of benefits to catches. Static gear fishermen were the strongest advocates for co-location of OWFs and MPAs with the caveat that static fishing activity remained possible within the OWFs or within a buffer zone that excluded other extractive activity surrounding the OWF. Although existing safety zones around pilings provide exclusion zones (~50m), laying a 'string' of pots within close proximity to a piling was required to benefit catches. Some static fishermen doubted benefits as, even with access, they still risked pots moving in bad weather and becoming entangled in turbines. The associated expense of retrieving or replacing them was questioned, as fishermen interviewed were also unsure of procedures and costs to recover or be compensated for lost equipment.

Additional deployment of artificial reef material was strongly advocated by static commercial fishermen and charter angling vessel operators. Again this was related to perceived economic benefits from potential species benefits such as crab, lobster and reef associated fish such as pollock, ling and conger. Identification of potential species augmentation benefits have been present since early reviews and have been expressed in fishermen's perceptions (Rodmell and

Johnstone 2005; Gray et al. 2005; Mackinson et al. 2006; Blyth Skyrme 2010; Alexander 2013). Ecological studies of OWFs (Chapter 4) have shown change in communities but no direct benefit to commercial species. The development of artificial reef and scour protection designs, as well as establishing the in-field effects of sediment, noise and EMF disturbance on commercial species are evidently priorities for future research to inform these planning options (Table 5.7).

It is important to consider future management options, such as effort restriction in OWFs if static fisheries were to make extensive use of these potential benefits. Pot and trap fishing effort has been shown to increase substantially in Lyme Bay following closure to mobile gears with many potting vessels doubling the gear they deploy (Mangi et al. 2011). The long term effects on species abundance and catch rates must be taken into account to avoid potential overfishing (McClanahan and Kaunda-Arara 1996; Miller and Hunte 2000; McClanahan and Mangi 2000).

As Mangi et al. (2011) highlight the initial perceptions of fishermen to measures such as area closures are often negative until long lasting positive effects from initiatives have been seen (Joyce 1989; Tylor and Buckenham 2003; Mangi et al. 2011). There have already been positive results in other European OWFs and wave energy developments for augmentation of commercial species (Langhamer and Wilhelmsson 2006; Reubens et al. 2010, 2013; Stenberg et al. 2011; Bergstrom et al. 2012). Similar positive associations of fish with gas rigs in European seas (Fabi et al. 2002; Scarcella et al. 2011), and emerging positive species benefits from the closure of Lyme Bay reefs to fishing for species with good and moderate recovery ability (Attrill et al. 2011) have been displayed. Greater acceptance and positive responses from the fishing industry may be apparent in the future if these trends continue and potential positive effects are maximised through effective mitigation at OWF sites. Both this study and previous accounts of fishermen's perceptions of fishing and renewable energy development interaction have been carried out, while many developments are being constructed or planned (Mackinson et al. 2006; Alexander et al. 2013). It is apparent that best practice suggestions for consultation, and mitigation requirements need to be acted on (Rodwell et al 2013). There is also a requirement for fishermen's experiences and perceptions to be recorded once all inshore OWFs have been constructed and operating. This will inform further decisions and adaptive management requirements on existing mitigation and planning options.

○→●*6.6 Summary*

To aid effective planning it is evident that greater communication and negotiation is practised between fishing and renewable energy industries (Rodwell et al. 2013). Potential for win-win scenarios, such as reducing scouring of sediment, using adequate rock or concrete scour protection that will also augment naturally occurring habitat potentially offer solutions. Effective understanding of the likely displacement patterns for mobile fisheries, and mitigation and management practices that enable ecologically and economically sustainable fisheries must also be sought (Linley et al. 2008; Wilson and Elliott 2009; Blyth Skyrme 2010). Fishermens regional knowledge and experience of environmental, social and economic changes following developments and management actions provide a valuable information source, in addition to statutory data. Region and/or gear type utilised were identified as the factors influencing responses to questions relating to all objectives.

i) Region

The different nature of regional fisheries, including gears operated and species targeted led to different issues being given priority. Similarly, existing pressures and challenges from other existing marine activities and regulations in each region led to separate issues being highlighted. Marine planning and MPA co-location decisions should therefore be considered on a case by case basis. Regional environmental, economic and social effects are important considerations as well as ecological and economic benefits from the co-location site. Ecological and socio-economic impact assessments of proposed MCZs and draft marine plans provide an existing opportunity to address these issues.

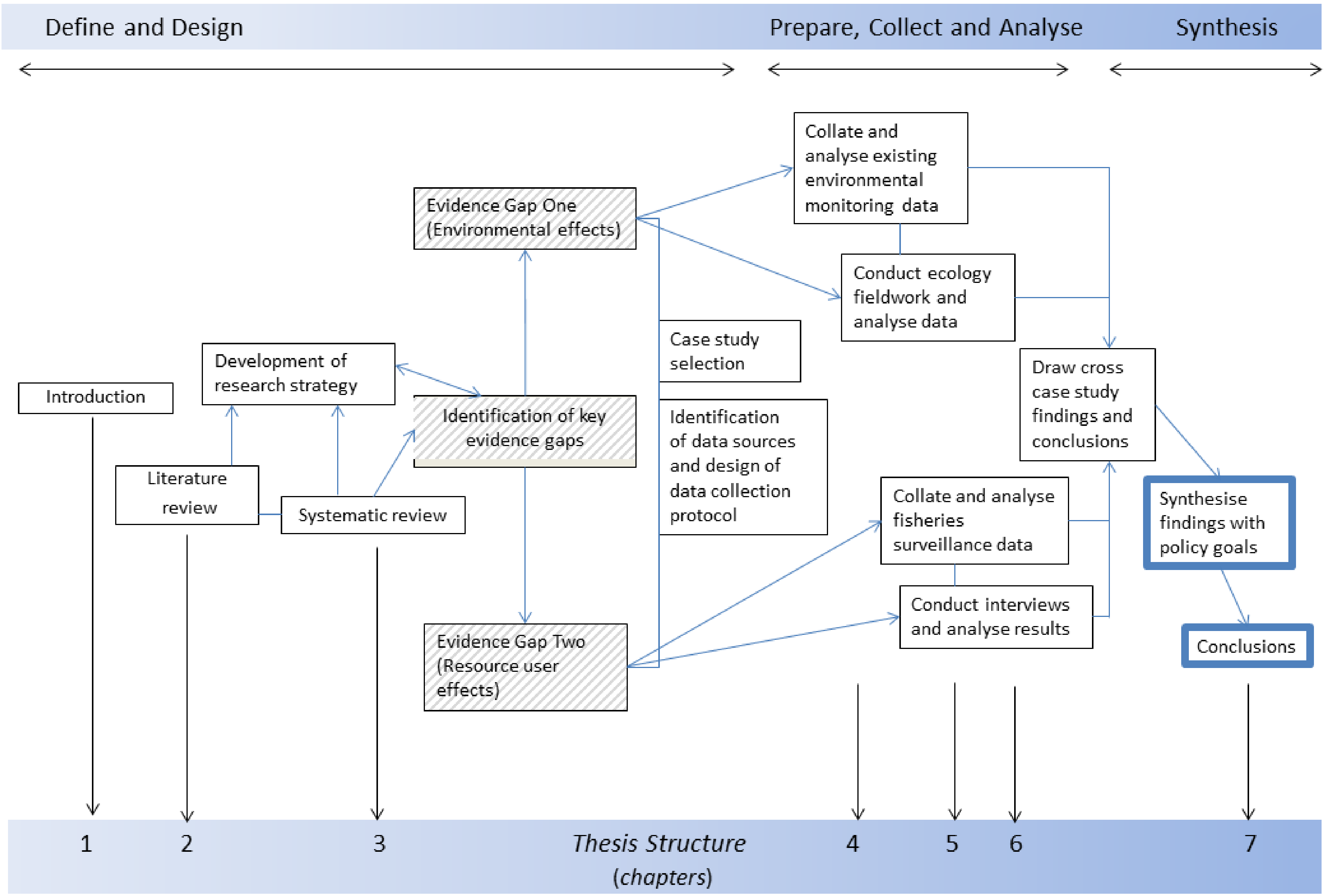
ii) Gear type

The greater impact for mobile fisheries observed in sightings data is also expressed in interview data. The effort displacement indicated by the activity data were confirmed in interviews. Respondents also provided reasons behind these activity changes (meeting objective 2 of the survey). Reasons included concerns over access, safety and lack of communication from developers on what activities were permitted. Taking safety and liability risks were discussed as not being worthwhile due to the lack of successful catches in proximity to case study OWFs. A number of respondents suggested target species for mobile gear fisheries had changed distribution, rather than increased in abundance at OWF sites. Co-location of OWFs and MPAs was suggested as beneficial, not purely to achieve conservation objectives but to reduce the additional fishing ground lost across the region.

Static gear fisheries also encountered loss of ground and also identified increased conflict from displaced mobile gear fishing activity. Positive effects were recognised by this sector, reflecting the smaller impact identified in analyses of activity data and positive effects to target species such as crustaceans. The positive effects identified most often included reduction of mobile vessel fishing activity and the potential of habitat created within OWFs to support target species, especially if enhanced scour protection/ artificial reef material is deployed.

iii) Informing marine planning and MCZ designation

The experiences recorded in interviews showed that the initial perceptions recorded in 2006 occurred once round one sites were operational (Mackinson et al. 2006). Both the positive and negative effects identified are likely to occur on greater and greater scales, as larger OWF are constructed to meet 2020 targets (Crown Estate 2010; DECC 2010a). Since this thesis study began 127 marine conservation zones have been proposed and 31 sites have been put forward for consultation by Defra as good sites for designation (Defra 2013). Of the 127 proposed MCZ sites, two include proposed OWF co-location zones (West of Walney rMCZ and North of Lundy rMCZ) (Defra 2013). A candidate Special Area of Conservation (cSAC) has been put forward that incorporates OWFs in the Greater Wash case study region. Marine spatial plans have also been released for consultation in the East region (including the Greater Wash case study region) and plans for the next region ‘South’ have begun the marine planning process (MMO 2013d). Marine plans provide a new approach to managing the seas, encouraging developments that consider the natural environment and informing sustainable use of marine resources. Individual plan policies will be consistent with national guidance in the Marine Planning Statement (MPS) and set out policies for managing marine resources and activities in each planning region (MMO 2013). The following, final concluding chapter draws the findings of the thesis into the context of the policies and objectives of MPA networks and marine plans.



Define and Design
Prepare, Collect and Analyse
Synthesis
Evidence Gap One (Environmental effects)
Collate and analyse existing environmental monitoring data
Conduct ecology fieldwork and analyse data
Case study selection
Development of research strategy
Introduction
Identification of key evidence gaps
Identification of data sources and design of data collection protocol
Draw cross case study findings and conclusions
Literature review
Systematic review
Collate and analyse fisheries surveillance data
Synthesise findings with policy goals
Conduct interviews and analyse results
Evidence Gap Two (Resource user effects)
Conclusions
1
2
3
Thesis Structure (chapters)
4
5
6
7

Chapter 7. Synthesis

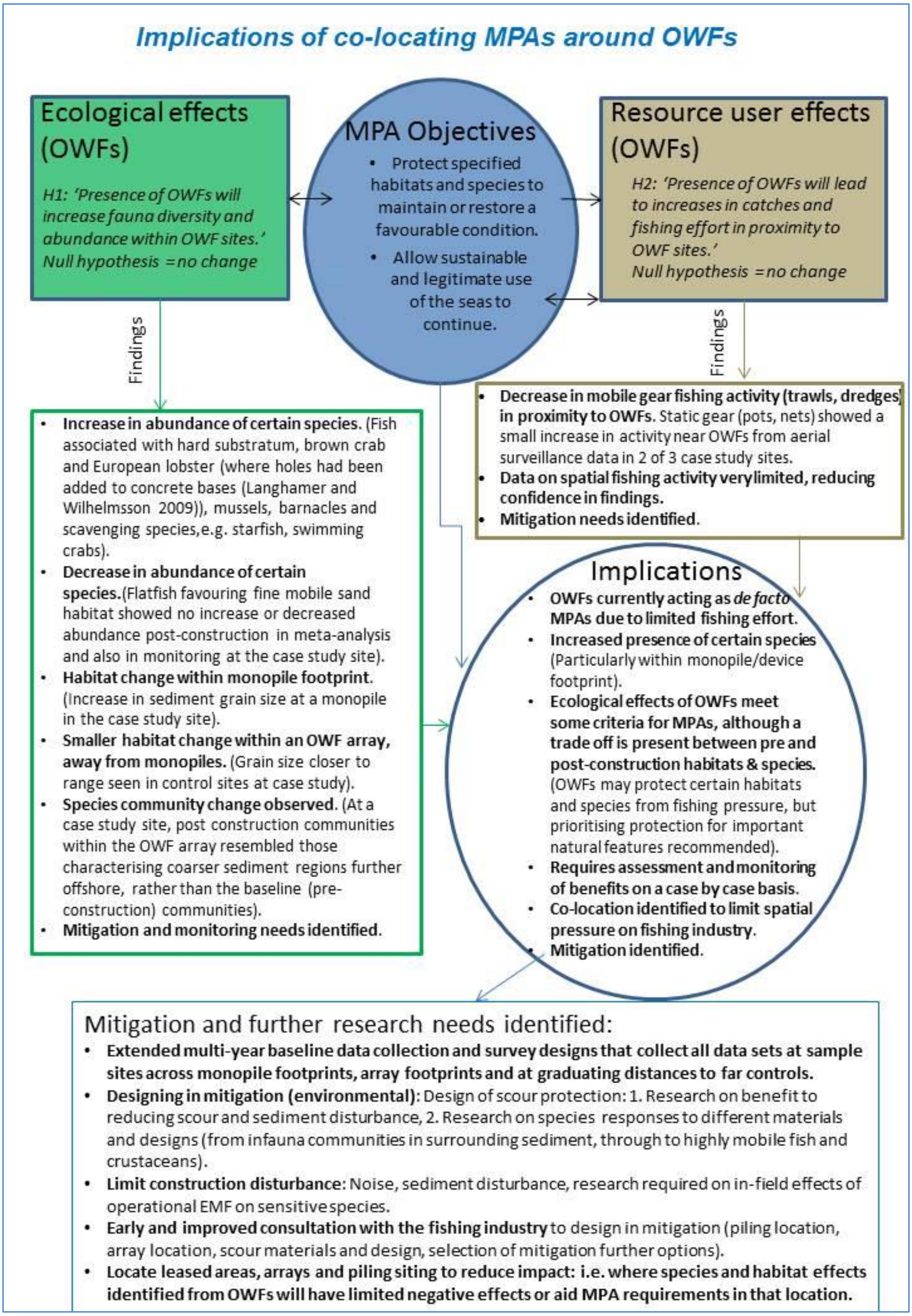
Co-location of OWFs and MPAs in relation to marine protected area goals

7.1 Introduction

The thesis has investigated the environmental effects of OWFs and social and economic effects of OWF development on a primary resource user. The ecological topics have been investigated through application of systematic review methodologies and meta-analyses of results from a number of existing sites. Analyses of existing monitoring data and primary data collection at a case study OWF were then undertaken at North Hoyle (Liverpool Bay, Irish Sea, UK). Social and economic effects have been investigated through analyses of spatial fishing effort and landings data within Liverpool Bay and two further OWF development regions in the UK. Face to face interviews were also conducted with fishermen in each region, to utilise fishermen's experience of effects, and record perceptions of potential management options.

This chapter summarises the main findings of this work and draws out the key lessons in respect to the implications of co-locating OWFs and MPAs (Figure 7.1). The discussions are based around the ecological effects of OWFs and the effects of OWF development on a primary resource user. Findings are discussed to identify if OWFs provide opportunity to protect, maintain and restore habitats and species of conservation importance and allow existing sustainable and legitimate uses of the sea to continue.

Figure 7.1. Conceptual diagram of findings of the thesis in relation to assessment of the implications of co-locating MPAs around OWFs.



The potential of co-location of OWFs within MPAs to meet the objectives of the two significant forms of MPA designation in UK waters (marine conservation zones (MCZs) and Special Areas of Conservation (SACs)), are discussed in relation to the results of this thesis and the wider relevant literature. The options for marine planning systems to balance marine conservation requirements and other marine activities are also discussed. There are currently two recommended MCZs that aim to incorporate co-location with existing OWFs in UK waters and one SAC. The specific conservation objectives in each of these conservation sites are reviewed in relation to findings of this thesis in appendices 3, 4 and 5.

7.2 Summary of thesis findings in relation to research objectives

The initial literature review identified a broad range of research requirements to assess the environmental effects of OWFs, and the resulting effects on resource users in relation to European and national MPA goals (Table 2.2) (Chapter 2). This made it apparent that an inter-disciplinary approach would be required to address both ecological and socio-economic research needs (Chapter 2). The two broad research needs (ecological and socio-economic) were linked by the need to understand effects of changes in species presence, abundance and distribution on a primary resource user. Identification of key evidence gaps to address in the study was met through a systematic review of ecological effects and resource user effects of artificial structures (Chapter 3). This process utilised a systematic methodology for identifying research priorities. This methodology was used as it could be repeated in the future (as OWF development, MPA designation and marine planning progress) to evaluate whether research needs have been met. The systematic review affirmed trends discussed in the broad literature review (Chapter 2). Effects of OWFs on species and communities and effects on fishing activity, catches and income were identified as key evidence gaps in relation to European MPA goals (Chapter 3). These evidence gaps were addressed in further analytical studies on ecological effects of OWFs (Chapter 4), and effects of OWF presence on fishing activity and catches to assess effects on a primary resource user (Chapter 5, Chapter 6).

i) Ecological findings

Meta-analyses within the systematic review provided initial results to address ecological evidence needs. However, these results also displayed limited confidence could be taken from trends, due to the limited data and therefore evidence base available at the time (Chapter 3). Initial meta-analyses results showed OWF and comparable artificial structures benefitted reef associated species, particularly brown crab (*Cancer pagarus*), brown shrimp (*Crangon crangon),* mussels (*Mytilus sp*.), reef associated gobies (*Gobius flavescens*), and wrasse (*Ctenolabrus rupestris*). Juvenile gadoid fishes also showed increased abundance in proximity to structures (Chapter 3). This was particularly true for concrete structures that incorporated some complexity such as holes. Soft sediment, sandbank associated species did not benefit from the new habitat provided by artificial structures. Flatfish (Pleuronectidae), and soft sediment associated gobies (*Pomatoschistus minutus*) decreased in abundance or showed no increase (Chapter 3).

The identified research need for analyses of multiple data sets on environmental conditions and fauna communities, over multiple years, extending beyond five years post-construction was approached in the ecological case study of North Hoyle OWF (Table 2.2, Chapter 3, Chapter 4). The mean sediment grain size increased near to a monopile from samples taken over pre and post-construction years. A change in benthic communities was identified within the OWF that displayed a weak correlation with sediment mean grain size. A much smaller change over pre and post-construction surveys was identified at greater distances from the OWF. Epifauna and fish communities also changed within the OWF post-construction, being dissimilar to communities at control locations, although species present were representative of species occurring in the wider region. The species responsible for the separation between epifauna and fish communities reflected the trends identified by meta-analyses (Chapter 3, Chapter 4).

Decrease in flatfish species plaice (*Pleuronectes platessa*) and sole *(Solea solea*) were identified within the OWF. Samples within OWF locations also displayed high abundance of juvenile whiting (*Merlangius merlangus juv*.) and scavenging species: common starfish (*Asterius reubens*) brittle starfish (Ophiuraidea) and crustaceans (*Liocarinus sp.*), consistent with trends suggested by meta-analyses (Chapter 3, Chapter 4).

Baited remote underwater video (BRUV) surveys in 2011 identified species communities within the OWF array remained similar 8 years post-construction to those present 2-3 years post-construction. Species communities in control samples to the east of the OWF were similar to those within the OWF in 2011. Communities to the west of the array were significantly different from both those within the array, and those to the east. Of the environmental variables collected at BRUV sample locations, salinity (lower in the east, close to the Dee estuary mouth, and increasing to the far west) and estimated sediment type provided a weak positive correlation with patterns in species community distribution. This indicated that in 2011 environmental conditions were also responsible for species community distribution.

The OWF was constructed in habitat consisting of highly mobile sediments, with high spatial variability in grain size, creating high natural variability in distribution of species communities (Winter et al. 2010). Although post-construction species communities remained dissimilar within the array to pre-construction samples, the lack of multiple year baseline data, and lack of collection of environmental variables in the FEPA monitoring samples, limited confidence in attributing changes solely to OWF presence. The change in species community, with increased abundance of a small number of scavenging species, require consideration in relation to the objectives of MPAs in sandbank habitats to maintain or recover those habitats and communities (Appendices 3, 4, 5). Benefits were identified to occur for specific species but negative effects were also apparent for other species. Increases or decreases in abundance of species targeted by commercial fisheries could affect the ecological and economic sustainability of local fisheries. Findings in relation to MPA benefits and disadvantages, and limitations in the evidence provided are summarised in Table 7.1 (further detail is provided in Table 4.16).

Table 7.1 Table of key findings related to ecological effects of OWFs in relation to MPA benefits and disadvantages and limitations in the evidence provided.

Section	**Findings / Effects**	**Summary**	**Confidence of effect/evidence**	**MPA co-location benefit / disadvantage**		**Mitigation options**	**Research priorities**
				Benefits	Disadvantages		
1. Ecological effects	▪Increase in coarser sediment within case study OWF.	▪Results suggested an increase in coarsersediemtn post construction within North Hoyle OWF array (from samples adjacent to a monopile).	**Limitations:** Seperation form natural variation (e.g. storm events, naturally highly mobile sediments with high spatial variability in grain size) limited by survey design.	▪Sediment grain size at samples at a distance from pilings remined within variation seen at control sites. (Reduced demersal trawling could lead to restoration of benthic communities at OWF in previously heavily trawled areas).	▪Coarser sediments provide inhospitable conditions for colonising infauna (Gray 1981). ▪Potential to alter sandbank habitats at monopile footprint scales.	▪Improve survey design witihin environmental monitoring, applying existing best practice. ▪Utilise rock scour protection.	▪Identifying effect of pilings and OWF arrays on changes in sediment, effect on dynamic nature and resulting effect on infauna communities in relation to individual MPA goals.
	▪Increase in scavenging species within case study OWF. ▪Community change within OWF.	▪Data from the North Hoyle OWF case study displayed an increase in scavenging species, 2-3 years post construction that was also identified 8 years post construction.	**Limitations:** A very similar species presence occurred at control sites to the east of the OWF in 2011 suggesting wider environmental conditions also influenced change. Survey design limited seperation of natural and OWF related effects.	▪Species that are increasing in presence and abundance require assessment in relation to individual MPA objectives. ▪Gadoid fish; whiting (*Merlangius merlangus*), potentially using food resources at pilings is of conservation interest as a Biodiversity Action Plan species (JNCC 2013).	▪As for benefits, species likely to increase in abundance need assessment against MPA goals.	▪As above, rock scour protection may increase biodiversity at the base of monopiles and limit disruption to surrounding sediment.	▪Effect of different designs of scour protection on species presence and species communities in relation to MPA goals. ▪Use of piling footprint habitat and array footprint by species of conservation importance.
	▪Change in abundance of specific species.	▪Meta analyses of existing studies and the North Hoyle case study identified similar species effects. Increase in Gadoid family fish, such as whiting, that can utilise the food and habitat resources created and decrease in certain sandbank specific species, such as flatfish.	**Limitations:** Decrease in certain species; sole and plaice, appears to have occurred across the North Hoyle region, although, 8 years post construction habitat outside the OWF appears of greater benefit to flatfish species.	As above.	As above.	▪Potential mitigation includes; greater sheathing of cables and reducing sediment and noise distrubance during construction ▪ Use of rock scour protection to reduce sediment scour and increase diversity of habitats and prey resources.	▪Telemetry and tracking methods to examine movement of fish species in relation to OWF sites, and stomach content analysis in relation to prey species available within the OWF and at control sites would aid investigation of changes in fish distribution.

ii) Resource user effects

Assessments of changes in fishing activity and landings pre and post OWF construction in three UK development areas were undertaken to assess resource user effects. Potential knock-on effects on ecological and socio-economic MPA goals were also considered (Chapter 5). Species effects identified in meta-analyses and analyses of ecological data were not identifiable in landings, although available data were limited in resolution to 4000 km^2 ICES rectangle areas. Effort distribution patterns did show different effects for mobile and static gear activity. Mobile gear fishing activity reduced near to OWF sites post-construction. Static gear fishing activity displayed smaller reductions, with potential increased effort within 2 km and within 10 km of OWF sites in two case study sites. Available spatial fishing activity data for vessels under 15m was limited for assessing change over time, reducing confidence in results.

Displacement of fishing activity has implications for the conservation of both habitats and species populations in the remaining grounds (Dinmore et al. 2002, Kaiser et al. 2006). Potential implications for fishermen from OWF development include: increased conflict, increased travel time and fuel costs, poorer catches and greater safety risks from increased time spent at sea (Mackinson et al 2006). If these identified effects occurred, they would have implications for both the success of an MPA network, and the social and economic impacts of marine spatial planning.

Face to face interviews with fishermen in each of the OWF development regions studied were undertaken, to gain resource user experiences and perceptions of effects of OWFs on fishing activity and catches. Interviews also provided the opportunity to record fishermen's knowledge of ecological and anthropogenic changes, and background factors affecting trends in each region (Chapter 6). Analyses of interviews showed the gear type used by interviewed fishermen influenced fishermens reported experience and perceptions of effects of OWF on activity and catches. Interviews highlighted the importance of previously existing factors affecting fishing activity in each region, and the cumulative effect of OWFs in addition to these (Chapter 6). Perceptions that were present in 2006, particularly negative concerns over effort displacement and reduced catches (Mackinson et al 2006) were indicated in experiences in 2011(Chapter 6). When considering management and spatial planning measures such as co-location of OWFs and MPAs, interviews highlighted the importance of considering existing pressures as well as effects of OWFs. Interview responses indicated that it is important to approach planning and management decisions on a region by region and case by case basis. This was due to the benefits and disadvantages available to different fishing practices, and differences between existing pressures in each region (Chapter 6). In relation to MPA goals, different management scenarios were identified as well as application of full no take zones. These include allowing static gear fisheries to operate within monopile safety zones (with limits on fishing effort), or co-locating MPAs and OWFs to reduce spatial pressures in remaining grounds (Chapter 6) (Table 7.2). For future OWF developments, it was identified more detailed assessment of existing activity and consultation is required. Mitigation could be provided at the planning stage, by adjusting turbine piling placement (to leave space for fishing to continue), or not developing on prime fishing ground to limit impacts of displaced fishing effort on remaining grounds (Chapter 6). Major findings are summarised in Table 7.2, further detail is provided in Table 6.7.

Table 7.2 Main findings on assessment of fishing activity changes and fishermen interview responses, including benefits and disadvantages to co-location of MPAs around OWFs and limitations in the evidence provided.

Table 7.2 Main findings from fishermen interview responses, including changes in activity and benefits and disadvantages from co-location of MPAs around OWFs and limitations in the evidence provided.

Section	Findings / Effects	Summary	Confidence of effect/evidence	MPA co-location benefit / disadvantage		Mitigation options	Research priorities
				Benefits	Disadvantages		
2. Resource user effects	▪Mobile fishing effort reduced within OWFs and in proximity to OWF sites (greater reductions for mobile fishing practices). Static gear fishing effort showed a very small increase in aerial surveillance data in 2 of 3 case study sites, but limited to 1-2 vessels sighted over all survey flights.	▪ Reductions were seen for both mobile and static gear types at 3 distance categories from OWFs, but were greater in proximity to OWFs. ▪Regional activity patterns suggested greater decreases for mobile fishing activity. ▪National trends also showed a decrease in registered vessels, fishing activity and catches over the last 10 years.	**Limitations:** Decreases also seen at further distances from OWFs in two of three case study regions. National decreases in vessels suggest other influences causing decline. ▪Limited data sets for activity of under15m vessels. ▪Over 15m vessels rarely used grounds R1 OWFs were located on.	▪Reduced fishing effort supports suggestions that OWFs act as *de facto* MPAs.	▪Lack of fishing activity within and in proximity to OWFs may suggest limited increase in populations of commercial species within the OWFs (and related emigration of commercial species).	▪Extensive mitigation options are identified in Table 5.7. e.g.: ▪Better consultation to limit placement of OWFs on valubale fishing grounds. ▪Reduction of noise and construction impacts. ▪Designing turbine bases or scour protection to enhance commercial species.	▪Monitoring or data collection techniques to identify important fishing grounds for vessels under15m (not carrying VMS). ▪Consultation and communication best practice. ▪Research into commercially targeted species repsonses to scour protection and trubine base designs.
	▪Interview responses reflected species specific effects and activity data.	▪Similar species as those identified in meta analyses and North Hoyle case study data were observed to increase or decrease in abundance. Increase (starfish, crustaceans, mussels, juvenile cod and whiting). Decrease or no change (flatfish, elasmobranchs).	**Limitations**: Only angling charter fishermen had been able to fish close to monopiles where species effects were anticipated to be greatest but reported few benefits (juvenile whiting).	▪Species of commercial and conservation importance identified to benefit.	▪ Elasmobranchs include many species identified as threatened by IUCN.	▪Perceived effects of EMF would require greater cable shielding, or deeper burying of cables but actual presence of these efects need further investigation. ▪Bubble curtains to limit construction noise. ▪Scour protection.	▪Identify if decreases are due to OWF and identify reasons why: ▪In field and laboratory research on effects of nosie, EMF and sediment change on commercial species. ▪Research species repsonses to scour protection designs.
	▪Interview responses provided interpretation of activity patterns.	▪Lost ground, challenges of fishing within OWFs, perceived effects of noise, increased suspended sediment and potential EMF were suggested to effect fishing effort (and catches) in proximity to OWFs.	**Limitations:** Economic issues such as compensation form developers and issues highlighted in industry discussions may influecne responses. A small sample size limited interpretation of results from Gt. Thames.	▪Results supported activity data that fishing activity was reduced in proximity to OWFs. This supports the suggestion of OWFs as *de facto* MPAs.	▪Reasons such as poor catches and changes in species abundance and distribution were linked to OWF presence.	(As above) ▪Mitigation of perceived reductions in species, and loss of fishing grounds through placing of OWFs away from valuable fishing grounds.	(As above) ▪Research to understand species specific repsonses to OWF related disturbance. ▪Species repsonses to scour protection and trubine base designs.
	▪Interview responses provided background information on existing pressures (and cumulative effect of OWF development in addition to these).	▪Certain issues common acrossregions in 2011. ▪Views of negative effects of exitisting aggregate extraction in Gt. Wash interviews suggested a region specific issue, linked to fishing practices in the region. ▪Address effects of OWFs on a region specific basis, paying atention to existing issues.	**Limitations:** ▪Interviews with fishermen outside of developemnt regions would have aided comparison. ▪Small sample size in the Gt. Thames. ▪Desire of interviewees to communicate issues of current regional concern may limit identification of further issues.	▪Interviews provided a means of aiding assessment of cumulative social and economic impacts on fisheries from multiple competing activities.	▪Interviews identified multiple uses of space were leading to fishing effort being concentrated in smaller areas, increasing potential ecological impacts to those locations.	As above. ▪Extensive mitigation options are identified in Table 5.7. e.g.: ▪Better consultation. ▪Reduction of noise and construction impacts. ▪Designing turbine bases or scour protection to enhance commercial species.	▪Apply research methodologies to assess cumulative ecological, social and economic impacts on fisheries and the marine environment (to assess economic and ecological sustainability)
	▪Interview repsonses identified priority mitigation and planning requirements.	▪A need for improved consultation was raised by most interviewed fishermen. ▪Benefits from MPA co-location were identfiied by both mobile and static fishermen. ▪A need to address piling noise and potentially EMF was also identified.	**Limitations:** ▪Question mentioned MCZs which may have lead to focus on this topic. ▪ Small sample size compared to the total number of fishermen active in the UK. ▪ Small sample size in Greater Thames.	▪Support from fishermen for co-location may aid acceptance and support of MPA zones within OWFs (and limit illegal fishing).	▪Support for MPAs appears out of an interest to limit MPAs in open grounds (which may be more suitable for protection).	The findings identified specific mitigation options: ▪Improved consultation. ▪Co-location with MPAs. ▪A need to address piling noise and potentially EMF.	(As above) ▪Consultation and communication best practice. ▪Research into species specific responses to OWF related disturbance and habitat change such as use of specific scour protection to aid MPA benefits.

7.3 Review of findings in respect to MPA and MCZ network criteria

Two visions of MPA goals are discussed in this section. Both visions have arisen as a result of the [Convention on Biodiversity 2008] (CBD) and the subsequent [EU Marine Strategy Framework Directive 2008] (MSFD) (Figure 2.3). The North-East Atlantic area is one of the designated areas under the MSFD where neighbouring states are to work together to achieve good environmental status (JNCC 2013). OSPAR defines MPA goals within the north-east Atlantic as being "*the purpose of protecting and conserving species, habitats, ecosystems or ecological processes of the marine environment."*

At a national level the MSFD acts as the over-arching framework for the UK Marine and Coastal Access Act 2009 (MCAA 2009) (Figure 2.3). The MCAA provides the legal mechanism in the UK to establish an ecologically coherent network of marine conservation zones (JNCC 2013). The Marine Conservation Zone Project was set up in 2008 and led by the Joint Nature Conservation Committee (JNCC) and Natural England, to identify and recommend a network of Marine Conservation Zones (MCZs) to Government. In addition to a suite of other MPAs the complete network aims to; '*to protect marine life while allowing sustainable and legitimate use of seas to continue* (JNCC 2013a).'

All MPA goals aim to achieve good environmental status by protecting marine life and the habitats that support it (JNCC 2013a). The findings of the ecological effects of OWFs within the thesis are relevant to reviewing if these goals can be met through co-location of OWFs and MPAs (Table 4.16, 7.1). The findings of the effect of OWFs on fishing activity and catches inform the goal of the UK MCZ network for MPAs to allow sustainable and legitimate use of the seas to continue (Table 6.7, 7.2). Furthermore, the effects of effort displacement as a result of lost fishing ground will present further ecological and economic considerations (Dinmore et al. 2002; Hutton et al. 2004; Kaiser et al. 2006). The following section reviews the findings of this study to identify the potential role of OWFs in relation to

MPA co-location and provision of an ecologically coherent network of MPAs (as required and under MCAA 2009).

Potential role of OWFs within an ecologically coherent network of MPAs.

Design of MPA networks has been identified to need to make efficient use of limited conservation resources, limit costs from reducing economic development opportunities, and limit costs of policing and enforcement (Lieberknecht et al. 2014). Unlike highly protected marine reserves which limit all human disturbance (Ballantine and Langlois 2008) MPAs, and in particular multiple use MCZs in the UK, protect specific features (habitats or species) and human use is managed in accordance with the protection required (JNCC 2011, 2013). Co-location of MPAs around OWFs may provide potential environmental and economic benefits (limit costs by providing environmental benefits and economic development), if resources can be protected within the same location as marine renewable energy industry development.

An efficient MPA network is recognised as protecting sites within a region that provide different features (habitats and species), that complement each other (rather than picking a series of hotspots containing similar features) (Lieberknecht et al. 2014). Highest value areas for protection are viewed as those providing high biodiversity (Hiscock and Breckels 2007), and high biodiversity combined with high vulnerability (Derous et al. 2007). Highest priority areas have been termed as *Ecologically and Biologically Significant Areas* (EBSA) (DFO 2004; Clarke and Jamieson 2007). The EBSA concept was applied to global oceans by the Convention on Biological Diversity (CBD 2008, 2010; Dunn et al. 2014). A set of 7 criteria are provided in relation to assessment of EBSAs (CBD 2008). Findings of this study in relation to EBSA criteria are summarised in Table 7.3. However, it is acknowledged that protecting only highest priority areas, particularly those with the same features, within a region may limit the effectiveness of an MPA network (Fox and Beckley, 2005). A suite of MPAs protecting different features within a region has been suggested as the best option, to provide ecological benefits and maintain sustainable activity within marine planning systems (Lieberknecht et al. 2014).

Table 7.3 Assessment of findings from this study in relation to EBSA criteria.

EBSA criteria	Provision in OWFs	
	Benefits	**Disadvantages**
• Uniqueness and rarity.	•Reduced fishing pressure on sublitttoral sandbank habitats between turbines, an EU Habitats Directive Annex 1 habitat.	•Changes to original sandbank habitat at monopile footprints. • Increase in sediment grain size in proximity to monopiles. • Species communities changes inside array in comparison to those pre-construction. •Improved monitoring required (longer baseline data collection) to separate sediment and species community changes from natural variation.
• Special importance for life history stages of species.	•Juvenile whiting observed in high abundance within North Hoyle OWF post construction in visual surveys in 2004 and 2011.	•Sandbank habitats in North Hoyle region an important nursery ground for flatfish species which showed a decrease within the OWF array. •Further research and improved monitoring required (longer baseline data collection) to separate from natural variation.
• Importance for threatened, endangered or declining species and / or habitats.	•Potential food resources benefit gadoid fish, including Biodiversity Action Plan species (whiting) (Bunker 2004; Reubens, 2011; JNCC 2013) •Reduced fishing pressure on sublitttoral sandbank habitats between turbines, an EU Habitats Directive, Annex 1 habitat.	•Sediment grain size increased in proximity to monopiles and species community changes recorded within monopile footprint and within OWF array samples.
• Vulnerability, fragility, sensitivity or slow recovery.	•Reduction of fishing pressure on substratum and communities between monopiles.	•Little evidence of benefits (occurrence) of vulnerable, fragile, sensitive or slow recovering species and communities.
• Biological productivity.	•Increased at monopile footprint, although dominated by a small number of species such as mussels and barnacles. • Limited increase away from monopiles.	•Further monitoring required to assess suitability of communities at monopile and on sandbank habitat away from monopiles for protection of required features on a case by case basis.
• Biological diversity.	•Increased at monopile footprint, although dominated by a small number of species such as mussels and barnacles.	•As above • Limited increase away from monopiles,
• Naturalness.	•Decreased fishing pressure may aid recovery of natural communities at distances from monopiles, dependent upon potential effects of scour and sediment dynamics	•Previous mobile sand communities replaced by hard substratum communities at monopile footprint. •Increase in coarse sediment at North Hoyle OWF likely to reduce colonisation of infauna. •Improvements to monitoring requirements required as suggested above.

The term ‘ecologically coherent MPA network’ has evolved within the UK (and Europe) to aid delivery of marine protection to achieve ‘good environmental status,’ under the MSFD (2008). Although EBSAs and associated criteria are given priority, additional planning principals are included in evaluation of sites to provide an ‘ecologically coherent MPA network’ (Lieberknecht et al. 2014). The findings of this study on the ecological and resource user effects of OWFs are summarised in relation to broader criteria complied by Lieberknecht et al. (2014) for evaluation of sites within an ecologically coherent MPA network (Table 7.4).

Table 7.4 Assessment of findings from this study in relation to ecologically coherant MPA network criteria.

Ecologically coherent MPA criteria	**Summary** (Lieberknecht et al., 2014)	**Provision in OWFs**	
		Benefits	**Disadvantages**
•Representativity / representativeness	•A network should represent the full range of biological features (species, biotopes, habitat types) present within the planning region, rather than limiting protection to a narrow range of priority features.	•Provision of potential food resources for regionally important species (e.g. whiting). •Reduced fishing pressure on sandbank habitat between monopiles.	•Changes to existing sandbank habitat and communities at monopiles. •Improved monitoring required to establish if community change within array (North Hoyle) due to OWF presence or natural variation. •Decreases in certain species requires further monitoring to identify if changes are due to presence of an OWF or due to natural variation.
•Adequacy / viability	•Individual sites need to be large enough to contain viable species populations, or other ecosystem components.	•OWF sites by the end of this study were covering 104sq km of sandbank habitat.	•Limited size of early OWFs
•Replication	•Resilience against catastrophic loss of any given site by selecting (replicating) sites with similar habitats in separate areas of the planning region.	•Multiple OWFs within a development region provides replication.	•Potential negative effects on pre-existing communities also replicated.
•Connectivity	•Species migrate and disperse leading to different areas being ecologically linked. Maintaining ecological links minimises risks of extinction in isolated sites as well as maintaining genetic diversity within populations. A network should provide habitat corridors, protecting sites along migration or dispersal routes, and ensuring sites are located close enough to allow movement or dispersal of key species between them.	•Potential to utilise OWFs in combination with protection of spawning grounds for Gadoid fish to increase protection for multiple life stages.	•Further research needed on risk of invasive or alien species. • Research needed on wind, wave and tidal devices influence on passage of larvae within existing dispersal routes.
•EBSAs	•Priority given to sites that fulfil EBSA criteria.	Addressed in Table 7.3	

Key findings in relation to MPA benefits

- The ecological chapters identified that hard substratum added by OWF construction supports high abundance of certain species (Ashley et al. 2013; Chapter 3, Chapter 4).
- This outcome is maximised with the use of scour protection or rock armouring that mimics naturally occurring reefs (Langhamer and Wilhelmsson 2009; Hunter and Sayer 2009).
- Changes were observed in sediment grain size, benthic infauna, epifauna and fish community data sets within the case study site (North Hoyle OWF), in comparison between pre and post-construction data sets. Communities 8 years post-construction were similar to those 2-3 years post-construction, suggesting a stable community.

Although changed from pre-construction communities, these communities closely resembled those occurring in coarser sediment in deeper regions in the Eastern Irish Sea (Ellis et al. 2000). Communities in 2011 also showed a correlation to a salinity gradient across the survey site, suggesting existing environmental conditions also influenced species distribution as well as presence of an OWF. Limited baseline data prevented confident assessment of change in relation to baseline conditions as the region consists of highly variable mobile sandbank habitat (Innogy 2002).

- High abundance of the Gadoid, *Merlangius merlangus* (whiting) and a small number of scavenging species within North Hoyle OWF 2-3 years and 8 years post-construction, suggested increased food resources, potentially from epifauna at monopiles, provide long-term benefits for these species.
- The loss of some pre-existing soft sediment habitat, increases in grain size in proximity to monopiles and smaller increases within the case study OWF array (North Hoyle), were likely to influence the abundance of previously common flatfish species.
- Reduced fishing activity was observed, particularly for mobile fishing practices near to OWF sites following construction, suggesting limited resource benefits and environmental, social and economic implications from potential redistributed fishing effort.
- Reduction in fishing activity within three regional case study OWFs may provide opportunity for epifauna species to become established (Auster et al. 2002). However, this effect was not identified 8 years post-construction at North Hoyle OWF.

Limitations of findings

- Limitations in the environmental monitoring survey designs and data collection were identified to limit confident separation of effects from natural variation in sediment and species communities.
- Limitations in the use of fisheries surveillance data, and lack of detailed spatial activity data for under 15m fishing vessels also prevented identification of changes in fishing activity and catches in relation to OWFs.

Further research needs

- This study highlighted the need for research applied to investigating sediment disturbance during OWF construction and operational phases.
- Further investigation into the most efficient scour protection and armouring materials, to both prevent sediment disturbance and increase habitat available were identified as priorities.
- Longer term baseline data collection of sediment, benthic fauna and fish communities is also required, with samples for each data set taken at the same sample locations, with graduating distance to far controls.
- This would provide necessary evidence to examine if the community change at North Hoyle OWF, present 8 years post-construction is due to annual variation, long term environmental cycles or OWF development.

7.3.1 Community change related to habitat change

Changes in benthic fauna communities in North Hoyle OWF post-construction showed a weak correlation to post-construction changes in sediment mean grain size. The increase in grain size in proximity to turbines has been predicted in existing reviews (Wilson et al. 2010).

The presence of monopile turbine structures is recognised to cause scouring of sediment (Innogy 2002). Environmental statements for North Hoyle predicted scour pits from 24m to 40m diameter and 6m depth (OSPAR 2010). Scouring processes will also increase the dynamic nature of existing highly mobile sediments (Coates et al. 2011).

The species shown to benefit from habitat within OWFs and those shown to be adversely affected, show habitat preferences relevant to the pre and post-construction conditions within OWF sites (Chapters 3 and 4). Infauna species that favour coarser sediment increased in abundance post-construction (Fauchald and Bellan 2013). Epifauna and fish species characterising assemblages within North Hoyle post-construction included scavenging species, and species that utilise hard substratum such as brittle stars (Ophiuroidae) and swimming crabs (*Liocarcinus sp*.) (Groenewold and Fonds 2000; Ramsay et al. 2000; Auster et al. 2001; Boos et al. 2010; Stohr et al. 2012). Common starfish, (*Asterias Rubens)* and hermit crab (*Pagarus bernhardus*) were also abundant across the study region.

Species that showed a reduction in abundance include flatfish species (Pleuronectidae), which forage on existing sandbank habitats and display preferences for finer sediment in which to bury for protection against predators (Gibson et al. 1994). Meta-analyses also identified high abundance of colonising epifauna, especially barnacles and mussels on OWF turbine structures (Chapter 3). These species potentially provide food resources for the abundant juvenile whiting (*Merlangius merlangus*) (Groenewold and Fonds 2000; Ramsay et al. 1998; Prokopchuk and Sentyabov 2006; Reubens et al. 2010, 2013), scavengers such as the starfish species (Ophiuroidae and *Asterius reubens*) (Norberg and Tedengrem 1995; Saier 2001; Boos et al. 2010; Stor et al. 2012) and the crustacean species (*Pagarus bernhardus* and *Liocarcinus sp*.) (Choy 1986).

7.3.2 MPA benefits from community changes

i) *Recovery and protection: habitats and species colonising monopiles.*

As OWFs provide a structural barrier to mobile fishing practices it is important to establish if sediment and communities within OWFs become stable over time, and represent those being sought for protection under MPAs. Displacement of fishing effort, especially from larger OWFs is likely to be considerable and increase pressure on habitats outside the protection of the OWF infrastructure (Dinmore et al. 2003; Kaiser et al. 2006). The co-location of OWFs and MPAs may provide a means within marine planning to reduce cumulative effort displacement from both OWFs and MPAs. Suitability of OWF habitats to regional MPA goals, however, are important to consider (Table 7.3, Table 7.4) (CBD 2008; Lieberknecht et al. 2014).

Epifauna fouling communities on OWF turbines in the Baltic Sea displayed similarity to communities on bridge pilings that had been in present for 60 years (Qvarfordt et al. 2006; Wilhelmsson and Malm 2008), suggesting a stable state had been reached in 2-3 years. The fouling communities recorded on turbines in Wilhelmsson and Malm’s (2008) study were dominated by mussel, *Mytilus sp.* and barnacle species. Similar *Mytilus sp*. dominated species assemblages have occurred on OWF turbines throughout the NE Atlantic. This has led Krone et al. (2013) to refer to an apparent ecological system change from OWF development in the German North Sea as the, ‘Mytilisation,' of the German Bight. Whilst these new assemblages provide prey resources for other species they are different from naturally occurring reef communities. It may be important to consider the development of such artificial structure communities when assessing MPA goals.

Similar artificial structures (oil and gas platforms) produced similar high densities of mussel species in temperate Californian waters (USA) (Love et al. 1994, 1999, 2000). The associated fish communities were also identified to be unique to each platform associated mussel mound, and different from communities at regional natural reefs (Love et al. 1994, 1999, 2000). The platforms studied in these examples had been present for up to forty years. Epifauna and fish communities colonising a steel shipwreck, which presented similar material qualities to OWF monopiles, also contained unique communities even after over 100 years (Perkol-Finkel et al. 2006). These findings indicate that communities present on OWF pilings may be present for the life of the structure. Although they provide a significant increase in biomass, communities may not necessarily represent or replicate naturally occurring communities (Wilhelmsson and Malm 2008; Krone 2013, CBD 2008; Lieberknecht et al. 2014).

ii) Recovery and protection: Species communities within an OWF array

The similarity between post-construction epifauna and fish communities on sandbank habitat within an OWF (North Hoyle) 8 years post-construction to those 2-3 years post-construction, suggests a stable community had established (from samples within the OWF but at a distance from the monopiles). As with communities observed on OWF monopiles and artificial structures this community had changed in comparison with baseline communities. Changes in sediment grain size and available food resources (due to epifauna colonising nearby monopiles) were likely to have influenced changes. It is important to consider if these ecological effects are relevant to individual MPA goals, and the goals of MPA networks within marine and coastal areas surrounding OWFs.

Although changed from pre-construction communities, post-construction epifauna and fish communities closely resembled those occurring in coarser sediment in deeper regions in the Eastern Irish Sea (Ellis et al. 2000). Communities in 2011 also showed a correlation to a salinity gradient across the survey site, suggesting existing environmental conditions also influenced species distribution. Limited baseline data prevented confident assessment of change in relation to baseline conditions as the region consists of inherently variable mobile sandbank habitat (Innogy 2002).

Duarte et al. (2014) identified that partial recovery to the baseline state prevails in recovery of marine and coastal ecosystems from impact or anthropogenic development. Recovery is often to a different stable state than that persisting prior to disturbance (Munkes 2005). Degradation from baseline (pre-existing) conditions and recovery often follow different pathways as environmental conditions may change in the interim (Duarte et al. 2014). Buffers may also act to maintain the degraded state (Duarte et al. 2014) (such as continuing increased background levels of suspended sediment, and change in sediment characteristics due to scour). Although species communities may be altered, ecological functioning may have recovered from the effects of construction activity, and the new situation may function in the same way as the original one (Elliot et al. 2007).

As the habitat and species present post-construction still represented regional conditions and species presence, benefits within North Hoyle OWF can still be identified within the category of ‘representativeness’ under MPA network criteria (Lieberknecht et al. 2014) (Table 7.4). Recovery of ecosystems is slow (Elliott et al. 2007; Duarte et al. 2014), typically succession is seen from ‘r’ strategist species (species with quick maturation, short life spans and short gestation periods, that thrive in disturbed habitats), to ‘k’ strategist species (large size, few offspring, late maturity and long lifespans) (Dolbeth et al. 2007). High abundances of a limited number of opportunistic species, common in disturbed areas were identified in the North Hoyle OWF case study (Ramsay et al. 1998; Groenewold and Fonds 2000). Although these regionally representative species and habitats are likely to be protected within the OWF from fishing pressure, additional mitigation may improve MPA benefits from OWFs. If measures were taken to reduce potential sediment disturbance during operation there may be opportunities for further species to increase in abundance in the site.

The best option to aid recovery is to remove the stressor (e.g. OWF monopiles) and allow conditions suitable for natural recovery (Elliott et al. 2007). As this option is not possible until the end of the operational lifespan of an OWF (~20 years), mitigation options to reduce stress on the environment and aid increases in biodiversity are available to managers. Disposal of drilling waste away from areas of impact to minimise sediment disturbance and use of bubble curtains to minimise noise, offer mitigation for impacts during construction. Optimum scour protection designs provide mitigation options to potentially reduce excess suspended sediment during operation.

iii) Habitat creation and increased carrying capacity

There is considerable evidence that marine reserves (full no-take zones) of various sizes provide increased density, biomass, individual size and diversity in all functional groups (reviewed by Halpern, 2003). While this evidence comes from existing reserves that have been specifically designed for conservation of habitat, species, or fisheries augmentation some exclusion areas associated with OWF arrays are beginning to show benefits to fish stocks, similar to those in MPAs (Gell and Roberts 2003; Russ et al. 2009; Wilhelmsson et al. 2006; Langhamer and Wilhelmsson 2009; Reubens et al. 2010, 2013).

OWF structures have been shown to provide prey resources and shelter for juvenile commercially targeted fish and all life stages of commercially targeted crustaceans (Langhamer and Wilhelmsson 2009; Stenberg et al. 2010; Reubens et al. 2010, 2013; Bergstrom et al. 2012). The structural barrier of the OWF and safety zones around turbines limits fishing activity, which would only be limited further by co-location within an MPA. The OWF infrastructure also provides a clear landmark to enforce MPA boundaries. This scenario provides a potential means of augmenting populations and therefore commercial stocks of these species.

The evidence of occurrence of juvenile life stages of species of commercial interest within OWF habitats, and evidence of feeding on epifauna at pilings is encouraging support of production effects (Pickering and Whitmarsh 1997; Bunker 2004; Stenberg et al. 2011; Reubens et al. 2010, 2013). Pouting (*Trisopterus luscus*) feeding on epifauna colonising monopiles in the North Sea displayed benefits, with similar health and fitness to fish feeding on natural habitat (Reubens et al. 2010, 2013). These fish, just as the juvenile whiting that were abundant in BRUV surveys at North Hoyle, potentially avoid being caught as by-catch in commercial fisheries. They also receive adequate food resources whilst utilising OWF habitat. The presence of regionally important, commercially targeted species and species of conservation interest (whiting, under the Biodiversity Action Plan (JNCC 2013)), using habitat within an OWF fulfils multiple EBSA criteria and therefore, MPA network criteria (Table 7.3, Table 7.4) (CBD 2008; Lieberknecht et al. 2014).

Further habitat augmentation to increase species carrying capacity benefits is recognised as a mitigation option to aid recovery or rehabilitation of degraded ecosystems (Cohen 1999; Elliott et al. 2007; Duarte et al. 2014). Debate exists over whether habitat creation provides enhancement for a whole system (e.g. marine and coastal ecosystems within an MPA network region) as one habitat is being replaced with another (Elliott et al. 2007). In the case of OWFs, deploying monopiles has occurred as an essential engineering requirement of the OWF. Designing in mitigation by providing scour protection that maximises habitat opportunities for commercial species, such as, reef associated fish, crab and lobster potentially increases overall goods and services available to primary resource users (Costanza et al. 1997). Rock scour protection, with material large enough to create complexity in the structure has been identified to benefit reduction of sediment disturbance and aid the greatest number of species (DECC 2008; Langhamer and Wilhelmsson 2009; Wilson and Elliot 2009; Wilson et al. 2010). Benefits to stocks of commercially targeted species will also aid elimination of the trade-off between achieving conservation and fishery goals (Gaines et al. 2010). Maximising habitat creation within monopile footprints may, therefore, provide OWFs with a role of commercial stock enhancement within an MPA network.

Limitations of this study and areas for improvement to inform the evidence base on implications of ecological effects for co-location of MPAs around OWFs are given in Table 7.5.

Table 7.5 Limitations and critique of the study of ecological effects of OWFs, including areas for improvement and further research.

Research Theme	Limitations (Critique)	Summary
Ecological effects (OWFs)	▪Limitations imposed by existing monitoring data.	▪Separation form natural variation (e.g. storm events, naturally highly mobile sediments with high spatial variability in grain size) was limited by existing survey design. Secondary data from environmental monitoring lacked extensive baseline data. Future studies could address this with increased use of alternative potential data sources for the Liverpool Bay region, such as modelling or empirical data, if available from institutions such as the National Oceanography Centre, Liverpool.
	▪Use of alternative analyses to examine changes in species communities pre and post construction: Biological traits analysis, functional groups.	▪Analyses of species community data utilised species presence and abundance data, analysed in PRIMER6. These are some of the most commonly applied measurements and techniques to express relationships in ecological data, further approaches and techniques have been developed to investigate the patterns observed in changes in species community distribution, particularly in response to human impact. These include: • Trophic group analysis: investigates differences in feeding mechanisms between assemblages (Roth and Wilson, 1998; Desrosiers et al., 2000,). • Biological traits analysis: considers a range of biological traits expressed by organisms to assess how functioning varies between assemblages (Bremner et al., 2006, Tillin et al., 2006). • Functional analysis of community structure such as the guild approach: considers main features of the species biology and the way in which they use a habitat, such a exploiting the same resources. (Nagelkerken and van der Velde, 2004, Elliott et al., 2007). As substratum and food resources were predicted to change following OWF construction infauna, epifauna and fish grouped according to biological traits or functional guilds may have provided a means of testing hypothesis related to changed habitat and resources in an OWF.
	▪Fuller assessment against recovery criteria and MPA network criteria.	▪This study took a broad approach to examining if species presence and abundance changed following OWF construction, and how resource users were effected. Well defined recovery and MPA network criteria available (CBD 2008, Elliott et al., 2007; Duarte et al., 2014, Lieberknecht et al., 2014), direct hypothesis related studies would be beneficial that addressed individual criteria (such as representativity, connectivity, importance of important life stages of species, naturalness, biological productivity) in respect to habitats and species communities within OWFs, possibly in comparison to naturally occurring habitats and features).
	▪Test individual hypotheses raised in reviews and studies on environmental interactions of OWFs which were published during the course of this study.	▪A broad approach was taken in this study following review of existing evidence identified key evidence gaps to assess MPA benefits from OWFs. During the course of the study publications provided further reviews of evidence gaps as well as theories, and hypotheses which could have been directly tested (e.g. Wilson et al., (2010)). Hypothesis on particular effects such as introduction of fine particles into the existing sediment environment from construction activities and scour having the potential to alter the overall sediment structure in the surrounding area, or in-field effects of piling noise on fish and EMF at operational levels could be investigated in individual studies.
	▪Conduct surveys at more than one site to provide comparison	▪Environmental monitoring data was only available for North Hoyle OWF despite pursuing other OWF site developers in other regions. BRUV surveys were only conducted at this site. Analyses of environmental monitoring data from other sites would have aided comparison. Two further OWF sites were present in Liverpool Bay, conducting BRUV surveys during the same period using the same survey designs would have provided greater evidence if changes observed in an OWF array were due to presence of monopiles or due to natural changes in sediment and other environmental conditions at a site.
	▪Investigate individual species effects tagging	▪Telemetry and tracking methods to examine movement of fish species in relation to OWF sites, and stomach content analysis in relation to prey species available within the OWF and at control sites would aid investigation of changes in fish distribution.

iv) Sustainable resource use

Fishermen operating towed gears displayed reluctance to fish within OWFs in interview responses (Chapters 5 and 6). Whilst this provides a *de facto* protection for habitats and species, trends in activity data and fishermen interview responses raised concern over fishing effort being displaced to grounds at greater distance from the OWF (Chapter 5, Chapter 6). Effort displacement is likely to place increased ecological pressure on unprotected grounds and increase economic and social pressures for displaced fishermen (Hutton et al. 2004; Hiddink et al. 2006; Mackinson et al. 2006; Greenstreet et al. 2009). Modelling of effort redistribution following area closures suggested that closure of lightly fished areas had the strongest positive effect (Hiddink et al. 2006). Closing large areas, especially those receiving high fishing effort, concentrated that effort within smaller spatial scales, thus increasing the regional impact on benthic communities (Hiddink et al. 2006). To counter positive effects of the area closure becoming outweighed by negative impacts of the redistributed effort, one option is to limit total fishing effort in addition to closures (Hiddink et al. 2006; Greenstreet et al. 2009). However, with quotas heavily limiting fishing effort this would put further economic pressure on fisheries, especially local inshore vessels with limited range to explore open grounds (Mangi et al. 2011).

During this study, operational OWFs were the smaller round one sites (typically 30 turbines and 10 km^2). These smaller sites were located on lightly fished inshore grounds and fit the case of the positive scenario identified in modelling studies (Hiddink et al. 2006). The trends in spatial activity across case study sites and interviews identified effort displacement of mobile gears to be a specific concern in relation to larger round two and three sites (Mackinson et al. 2006, Chapter 5, Chapter 6). The larger sites, especially the round three sites of over 6000 km^2 will create greater effort displacement. If displacement is not mitigated and potential positive benefits of these OWF sites are not maximised, then the overall effects may be negative. Region wide assessment of the positive and negative ecological and economic effects of OWF development and MPA designation, taking into account the knock-on effects of effort displacement stands out as a high priority for the current marine planning processes being developed in the UK and across Europe (Ehler and Douvere 2009; MMO 2013b). Greater habitat augmentation within OWFs may aid planning by enhancing stocks and mitigating loss of fishing ground and displacement in a region. At larger OWF sites placing of turbines and infrastructure to enable open fishing zones, taking measures to limit sediment disturbance and augment habitat and closing remaining areas of the OWF to fishing may aid conservation and fishing objectives.

To aid delivery of an ecologically coherent MPA network within a region, addressing the current limited benefit to commercial stocks from OWFs, identified in Chapters 5 and 6 is required. These mitigation methods may also limit the negative effects of effort displacement (Hutton et al. 2004). Mitigation options have been suggested to aid carrying capacity of commercial species within OWFs, through habitat creation (Table 5.7) (Mackinson et al. 2006, Blyth-Skyrme 2010). Further marine planning and mitigation options have also been identified and reviewed (Table 5.7) (Mackinson et al. 2006; Blyth-Skyrme 2010). To prevent increased fishing pressure and negative environmental impact in remaining grounds, certain fishing practices (static nets and pots) may be used within OWFs with limited impact on conservation objectives. Larger OWFs may also provide opportunity for both closed and open zones to fishing activity, combined with habitat enhancement and practices such as lobster seeding from hatchery reared stock (Table 5.7) (Mackinson et al. 2006; Blyth-Skyrme 2010). To reduce further spatial pressure in remaining grounds, industries competing for space with traditional fishing practices, such as aquaculture, may be integrated within OWFs (Buck et al. 2004; Syvret et al. 2014). Although not directly associated with the implications of co-locating MPAs around OWFs, these alternative approaches may be beneficial in regional planning scenarios, particularly where few criteria to aid a regional network may be met by a particular OWF site (Table 7.3, 7.4).

Limitations of this study and areas for improvement to inform the evidence base on implications of resource user effects for co-location of MPAs around OWFs are given in Table 7.6.

Table 7.6 Limitations and critique of the study of resource user effects of OWFs, including areas for improvement and further research.

Research Theme	Limitations (Critique)	Summary
Resource user effects (OWFs)	▪Limitations imposed by data confidentiality / lack of monitoring of under 15m vessel activity	▪Monitoring of vessels under 15m consisted only of aerial surveillance data, designed for enforcement is recognised to be of limited applicability to quantifying spatial fishing effort (Vanstead and Silva, 2010). Data confidentiality prevented vessel identification which could then be associated with landings data to establish location of catches for both VMS and aerial data. Economic sensitivity also prevented IFCAs in the Greater Thames region and Welsh sharing sightings data. Vessel monitoring systems under trial for under 15m vessels and fishermen's plotter data would provide valuable data resources for future assessment of changes in fishing activity (MMO 2012; Crown Estate 2011)
	▪Interviews from a sample of fishermen from regions with no OWF development.	Fishermen interviews in 2011 provided background information on reasons for changes in activity and catches over the past 10 years. All fishermen were from regions affected by OWF development. Additional interviews from a sample of fishermen in other regions with no OWF development would have examined which background conditions were relevant across all regions, and also provided a comparison for impressions/experiences of changes in catches and activity patterns.
	▪Greater sample size in the Greater Thames region.	All available fishermen were interviewed in Liverpool Bay and the Greater Wash regions during field trips of up to a week. Time and resource constraints meant fewer days were spent interviewing fishermen in the Greater Thames region. This resulted in a low sample size from a region with a very active fishery and all interviews being with mobile gear fishermen providing limited comparison within the region and between other regions.
	▪Conduct interviews with other stakeholders, developers, other industries, public, environmental conservation bodies and marine planners.	▪The study focused on assessing effects on resource users but marine planning and MPA networks affect a wide range of stakeholders. Co-location in particular effects the renewable energy industry in increased monitoring costs and protocols (Defra 2012). Perspectives on benefits and disadvantages of co-location of OWFs within MPAs form a wide range of stakeholders would have been beneficial to this study.

7.4 Marine planning

This study was conducted in respect to a changing policy landscape. Significant policy drivers relating to protection of biodiversity, renewable energy generation and fisheries management have led to multiple uses of the marine environment competing for space (Qui and Jones 2012). This has led to the development of marine spatial planning to balance competing interests. MSP is defined by Ehler and Douvere (2007) (following the first international workshop on MSP) as *''a public process of analysing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic, and social objectives that are usually specified through a political process.''* In many cases a clash is apparent between the economic use of the sea (and demand for economic growth) and the drive for protection of biodiversity and ecologically focused management of the sea (Qui and Jones 2012). Co-location of activities, particularly the co-location of OWFs and MPAs potentially provides multiple benefits: balancing the energy needs of society, the economic growth of an industry and protection and recovery of features of ecological importance. The provision of habitat that may increase abundance of commercially important species is also identified to aid regional fisheries.

The enactment of the Marine and Coastal Access Act (MCAA) in November 2009 required the newly formed Marine Management Organisation (MMO) in England and the existing Welsh Government (WG) to produce marine plans for their inshore and offshore waters. The Marine Policy Statement (MPS) guides marine planning in the UK and encourages co-location, as expressed in sections 2.2.1 and 2.3.15 (of the MPS), which state: *"promote compatibility and reduce conflict"* and *"reduce real and potential conflict, maximise compatibility between marine activities and encourage coexistence of multiple uses."* The first draft marine plans for an English and Welsh marine planning area, the English East region, containing the Greater Wash case study site reflected this in draft plan policy 'GOV2,' which states: '*Opportunities for co-existence should be maximised wherever possible.'* Although, co-existence is supported by the MMO it is required that such activity or development is compatible with the conservation objectives for the site features and does not impact on site integrity.

Practical examples of proposed co-location exist in UK waters. Proposed MCZ co-location zones (pCLZ) are present at West of Walney recommended MCZ (rMCZ), in the Irish Sea and North of Lundy rMCZ off the coast of North Devon, UK. Co-location of OWFs in the Greater Wash region would also be required with a Natura2000 site, the Race Bank and Inner Dowsing pSAC. Considerations of findings of this study in relation to rMCZ objectives for each rMCZ pCLZ site are discussed in detail in appendices 3 and 4. Considerations for Inner Dowsing, Race Bank and North Ridge cSAC are discussed in appendix 5.

Existing licensing and legislation provides opportunities for assessment of benefits and disadvantages identified in findings of this study. Individual OWF developments are subject to being accompanied by an Environmental Statement under European Environmental Impact Assessment (EIA) Directive requirements. Developments are also subject to Cumulative Impacts Assessments (CIAs), whereby the impacts of multiple projects or activities are assessed to examine if cumulative impact is greater than, or different to that of each individual project. CIA is a project-level assessment, carried out as part of a response to the requirements of the European EIA, Habitats and Wild Bird Directives, designed to identify potentially significant impacts of developments and possible mitigation and monitoring measures (Renewable UK, 2013). The mitigation and monitoring requirements identified in this study are therefore directly relevant to identification of adequate mitigation and monitoring within these processes.

Developments that are likely to affect Natura 2000 sites such as Inner Dowsing, Race Bank and North Ridge cSAC are subject to additional environmental assessment, in addition to EIA and CIA requirements. The EC Habitats Directive (92/43/EEC) requires that where a plan or project is likely to have a significant effect on a Natura 2000 site, either individually or in combination with other plans or projects, it shall be subject to Appropriate Assessment (AA) of its implications for the site, in view of the site's conservation objectives. In accordance with the Directive, in-combination effects need to be considered for relevant Natura 2000 site features (habitats and species). The process of screening for likely significant effects and, where appropriate, the undertaking of an AA is known as a Habitats Regulations Assessment (HRA) (Renewable UK, 2013).

Planning Authorities, including the MMO, are also subject to the European Directive 2001/42/EC "*on the assessment of the effects of certain plans and programmes on the environment,"* known as the Strategic Environmental Assessment, or SEA Directive. This process provides a further route for findings of this study and required monitoring and mitigation to be applied to co-location scenarios. Screening and scoping options for co-existence of activities have been undertaken by the MMO for the East Marine Plan region (MMO 2014). The SEA process, and the tools under development to achieve it provide a direct application for assessment of ecological and resource user effects of OWFs, as well as application of monitoring and mitigation requirements to aid sites to benefit MPA goals. For instance, habitat sensitivity to potential cumulative pressures caused by fixed foundation offshore wind has been assessed within the East Marine Plan area as part of the current 'Evidence and Issues Report' (MMO 2014a).

7.5 Conclusions

In conclusion the findings of this study identified opportunities for OWFs to provide a role in an ecologically coherent MPA network, although due to anthropogenic disturbance OWF sites were unlikely to meet requirements of full, highly protected marine reserves (Fig 7.1). Mitigation and management options were also identified that could potentially limit negative ecological effects, and negative effects on existing resource users within OWFs (Fig 7.1). In summary, certain species were identified as ecological winners and losers from OWF development. Within monopile footprints at a case study site coarser sediment and hard sub-stratum habitat was present, but at the loss of existing sandbank habitat. The species which can exploit these conditions appear to benefit, whilst those that utilised pre-existing habitats exhibited little benefit at the site its-self.

These ecological trends can be identified in the gains and losses experienced by fishermen. Fishermen using static gears, targeting species that utilise hard substratum displayed smaller decreases or even increases in activity near to OWF sites (although data sets provided limited confidence in these results). Fishermen utilising static gear also identified positive effects in interviews, especially if artificial reef materials were deployed and mobile fishing practices discouraged from OWF sites (Chapter 6). Fishermen using mobile gears experienced displacement, and reported reduced catches near to OWFs (Chapter 6). Even as *de facto* MPAs, OWFs could provide a habitat creation role, by increasing carrying capacity for exploited species (Cohen 1999; Elliott et al. 2007; Duarte et al. 2014). This may aid pressure on commercial fish and crustacean stocks and rehabilitation of ecosystems to enhance sustainability of regional fisheries.

Lack of extended baseline data and the highly variable nature of mobile sandbank habitats prevented this study from establishing if habitats and species communities within an OWF array, but away from monopiles, would benefit regional MPA networks. Individual conclusions are summarised in more detail below:

- OWFs studied in three case study regions currently act as *de facto* MPAs due to lack of fishing effort.

Fishing activity using mobile gears (trawls and dredges) decreased near to OWFs. Although fishing activity using static gears increased near to an OWF in 2 of 3 case study locations limited sightings were responsible, suggesting very little annual activity. No activity was recorded within an OWF array post-construction. Although data on spatial fishing effort was very limited, reducing confidence in findings, the results suggested little benefit was identified by fishermen from fishing near to OWFs. It must also be considered that other factors, such as safety considerations and financial compensation payed by OWF developers may have influenced this pattern.

- OWFs met certain criteria of a multiple use MPA, to provide benefits within a network of MPAs (Table 7.3, 7.4). Improved mitigation and management approaches were identified that could aid benefits.

A review of findings of this study in relation to key criteria for Ecologically and Biologically Significant Areas (EBSAs) (CBD 2008), revealed potential links between OWFs and key MPA site selection criteria. Although OWFs were not identified to provide all 7 EBSA criteria and in particular '*naturalness*' may not be met as the pre-existing sandbank habitat has altered within monopile footprints, some links to key criteria were apparent (Table 7.3):

-*Importance for life history stages of species*. Juvenile whiting were observed feeding on epifauna present on monopiles within North Hoyle OWF 1 year post-construction. The species was also recorded in high abundance in baited remote underwater video surveys 8 years post-construction). Liverpool Bay provides an important nursery ground for this Biodiversity Action Plan Species (JNCC 2013). The habitat and food resources provided within North Hoyle OWF (at monopiles in particular), would appear to provide an important potential resource, aiding survival of juvenile whiting. The presence of this species utilising habitat within the OWF also provided links for the OWF to further criteria of EBSAs: *'importance for threatened, endangered or declining species and or habitats.'* Evidence for presence of factors relating to the criteria of '*biological productivity,'* and, '*biological diversity,'* were also present.

A full case by case assessment would be required however to take into account negative effects, such as changes from pre-existing habitats at monopile footprints and reduction in abundance of previously common species post-construction. It must also be considered that pre-existing natural habitats that meet EBSA criteria may provide greater benefit within an MPA network than artificial habitat within an OWF. Criteria for assessment of sites within an ecologically coherent MPA network were also identified within an OWF (Lieberknecht et al. 2014). The presence of species of conservation importance provided a link to, '*representativity.' 'Replication,'* is also provided by multiple OWFs being present within regions in the UK. '*Connectivity'* is provided by the open marine location of OWFs and as discussed EBSA criteria are present. Again it must be considered that natural sites that provide similar criteria may be more beneficial to an ecologically coherent regional MPA network. Reduction of sediment disturbance, through adequate scour protection may limit excessive variation in soft sediment habitats. Diversity of habitats may also limit dominance of communities within an OWF array by opportunistic species. For instance, complex rock scour protection is likely to enhance abundance of larger, commercially exploited species within monopile footprint habitats (Langhamer and Wilhlemsson, 2009).

- Specific habitat and species benefits were seen.

Meta-analyses of changes in species abundance pre and post-construction showed reef associated fish species and crustaceans, as well as mussel and barnacle species increased in abundance at artificial hard substrate structures. This was also apparent within OWF monopile footprints, in particular where stone or rock scour protection had been used.

- Certain species showed limited benefit from the presence of an OWF.

Certain flatfish species, with preference for sandbank habitat decreased in abundance post-construction at OWF sites in meta-analyses and between pre and post-construction monitoring at North Hoyle OWF. The North Hoyle OWF array was constructed on a site with variable sediment, including gravels (Innogy 2002). Pre-construction sediment grain size inside the OWF site was similar to samples outside the array pre-construction, but significantly larger post-construction (particularly adjacent to a monopile) (Chapter 4). This suggests changes in sediment grain size may have influenced species distribution. Lack of long-term baseline data for sediment and fauna prevented further separation of effects of presence of the OWF from natural variation in grain size at the site. This identifies an area that could be improved in monitoring. As multiple OWF developments are being undertaken within regional locations, a joined up approach between developers and stakeholders may provide a cost-effective means of collecting more extensive baseline data (MMO 2013c).

Final conclusions:

- Benefits and disadvantages can potentially be managed and mitigated through deploying scour protection designed to reduce sediment disturbance. Use of larger rock scour protection may also provide beneficial hard substratum habitat for commercially exploited species. (Risks must be assessed for existing resource users, for instance: deploying extra obstructions on the sea bed that may further limit fishing ground for mobile gear fisheries).

- Potential identified for OWFs to provide a role, increasing stock of certain commercially targeted species to aid sustainable fisheries, or protecting life stages of fish of commercial importance within an MPA network.
- Further monitoring and research needs were identified in the following areas:

- Extended multi-year baseline data collection and survey designs that collect all data sets at sample sites across monopile footprints, array footprints and at graduating distances to far controls.

- Designing in mitigation (environmental): Research is required into design options of scour protection to, 1. Assess benefit of designs to reducing scour and sediment disturbance and, 2. Assess species responses to different materials and designs (from infauna communities in surrounding sediment, through to highly mobile fish and crustaceans).

- Identifying methods to reduce construction disturbance, for instance: reducing noise disturbance during piling through use of bubble curtains. Reducing increased effects of suspended sediment by limiting re-suspension and deposition of cuttings in sensitive areas. Research into in-field effects of operational EMFs on EMF sensitive species was also identified as a priority area.

- Early and improved consultation with the fishing industry to design in mitigation (monopile location, array location, scour materials and design, potential for fisheries closures within arrays, or application for several or regulating orders for shellfish fisheries).

- Locating leased areas, arrays and piling siting to reduce impact: i.e. where species and habitat effects identified from OWFs will have limited negative effects, or aid MPA requirements in that location.

- Management considerations relating to the conclusions are identified are summarised in Table 7.7:

Table 7.7 Management and mitigation considerations identified in the study for ecological and resource user effects of OWFs and implications of co-locating MPAs around OWFs.

Topic	Options to Consider	Benefits Provided
Ecological effects		
Licensing	▪Extended temporal baseline monitoring (sediment, infauna, epifauna, fish).	▪Aid interpretation of change from baseline state and relationship of 'recovered' environmental and fauna communities to a baseline state.
	▪Monitoring design improvements, collection of all data sets at the same sample locations and sample locations to examine piling footprints, array scale footprints and effect of distance from the array.	▪Aid analyses of interactions between environmental characteristics and fauna responses. ▪Aid separation of development effects from natural changes in variables such as: sediment grain size, salinity, organic content, prey availability.
	▪Long term collection of post construction data (not necessarily at as many sample sites).	▪Aid identification of community changes in relation to natural and anthropogenic changes in habitat and identification of a 'recovered' stable state.
Mitigation to aid recovery of habitats and species.	▪Minimise construction effects from increased suspended sediment and noise.	▪Reduce initial impact to minimise recovery required. (e.g. Reducing noise impacts through bubble curtains may reduce negative impacts on fish and associated trophic level interactions (Perrow et al., 2011)).
	▪Minimise sediment disturbance from scour during operation with appropriate scour protection.	▪Reduce risk of additional suspended sediment and sediment disturbance adding to existing natural processes. Providing conditions in remaining area, at distance from monopiles as close as possible to that occurring naturally.
	▪Investigate in-field species specific responses to EMF for elasmobranch and flatfish species.	▪Provide evidence on questions over potential responses of elasmobranchs and flatfish to EMF and address if a need for mitigation is required.
Resource user effects		
Mitigation to aid benefits from OWF sites and reduce negative effects of effort displacement.	▪Information clearly publicised on what fishing activities are permitted within each OWF. Location of hazards and protocol in case of emergency or entanglement of equipment.	▪Reduce increasing fishing pressure on remaining grounds (if OWF sites/areas within OWF sites do not provide benefits from protection).
	▪Formulate industry wide best practice for marine planning regions on early consultation with fishing industry (using consistent points of contact across each stakeholder group).	▪Provides early identification of issues and mitigation solutions.
Planning		
Options to aid marine spatial planning decisions.	▪Case by case review of benefits and disadvantages identified for OWFs against requirements of a regional MPA network.	▪Utilise benefit of features within an OWF and protect habitats and species present against further impact such as extractive activity.
	▪Applicability of additional habitat creation to augment commercially exploited species or species of conservation interest.	▪As habitats at monopile are already anthropogenically altered ensure positive effects are maximised (such as use of scour protection material that provides beneficial habitat.
	▪Naturally occurring habitats require priority in MPA selection as communities within OWFs may provide similar functioning to naturally occurring communities but different species presence.	▪Anthropogenically altered habitats often show recovery trends with stable communities reached that are often different to naturally occurring ones, although functioning may be the same (Elliott et al., 2007; Duarte et al., 2014). A trade-off is apparent, as naturally occurring habitats and species may provide greater benefit to regional MPA networks.
	▪Options to limit further stressors on sandbank habitat between monopiles. Limiting fishing activity, particularly mobile practices. Through full exclusion in smaller OWFs and zoned exclusion in larger sites.	▪Enable sandbank habitat between pilings to benefit from full MPA status or de facto MPA and recover to final state.
	▪Where OWFs provide limited benefits to regional MPA networks co-location of competing industries such as integration of aquaculture practices may aid spatial pressures on remaining areas.	▪Reduce cumulative loss of ground to fishing activity and further economic social and environmental impacts from displacement. ▪Reduce stressors on remaining habitats outside of OWF footprints.

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Appendix 1. *Table displaying study methods and findings of marine renewable and artificial reef associated structures.*

Structure	*Reference*	*Habitat*	*Structure details*	*Methodology*	*Survey design*	*Benthic species effect*	*Fish effect*	*Commercial species effect*	*Fishing catches effect*	*Similarity to natural habitat*
OWF	Andersson et al 2009	sand, mud gravel, 3-10m deep	6 OWF, steel pillars, 6 OWF, concrete pillars	Visual census, PRIMER	Temporal, Spatial	Increase, *A.scabra*, *C.intestinalis* *B.improvisus*	Increase, *G.flavescens*, *Pomatoschistus.spp*	No increase	not studied	Dissimilar
OWF	Wilhelmsson et al (2006)	2 sites, 6-8m deep, Glacial boulder Ridges/shoal	5 OWF turbine, 7 OWF turbine, steel , no scour protection.	Visual census, PRIMER	Spatial (Temporal day)	not.studied *M.trossulus*	Increase *G.flavescens* *P.minitus*	yes, turbot	not studied	not studied, observed dissimilar to surrounding
OWF	Wilhelmson and Malm (2008)	2 sites, glacial ridges, soft sand, 8m deep	5 OWF turbine. 7 OWF turbine, steel, no scour protection	Visual census PRIMER	Spatial	Lower abundance and diversity than natural reef, algae diversity low Increase in *Gammarus spp*. *Balanus spp*. *M.trosullus*	not studied	yes, crustaceans x2 on turbines	not studied	dissimilar with invasive and locally absent species present
OWF	Wilhelmsson et al (2006)	24 artificial reefs, sand/silt bottom	24 reefs, concrete, roof tiles, 8 3m high pipes, 8 1m high pipes	Visual survey ANOVA, Kruskall Wallis, Mann Whitney U	Spatial, Temporal	Increase, Hydrozoa Ascidiacea *Balanus spp*. Red algae	Increase, *Gobius niger* *Ctenolabrus rupestris*	Yes, *G.morhua* *C.pagarus* *Pleuronectidae spp*.	not studied	increase in abundance but diversity remains similar. All reef show increase. Highest with pvc pipe.

Structure	*Reference*	*Habitat*	*Structure details*	*Methodology*	*Survey design*	*Benthic species effect*	*Fish effect*	*Commercial species effect*	*Fishing catches effect*	*Similarity to natural habitat*
OWF	Vatenfall et al (2006)	14-20 km offshore	80 turbine steel	hydro acoustic, Gill nets, Trawl, General Linear Model, ANOVA.	Spatial (Temporal, 2 days)	not studied	not before/after diel change nocturnal increase	yes	not studied	similar
OWF	Carstensen et al (2006)	sand/silt glacial deposits, 6 - 9.5 m deep. And non OWF ref. area	72 turbines, steel	T-POD monitoring, mixed linear models, BACI analysis.	Temporal	not studied	Decrease in porpoise but limited spatial data and during construction only.	not studied	not studied	dissimilar
OWF	Sorenson (2002)	2 - 6 m deep, Sand /gravel	11 turbines, steel	gill netting	Spatial Temporal	INSUFFICIENT DATA			fisher statement: turbot decrease	
OWF	Dong Energy (2006)	2 sites 14-20 km offshore, 10km offshore	80 turbine 72 turbine	gill nets, trawls, hydro acoustic,	Temporal Spatial	not studied	same as reference nocturnal increase	same as ref	not studied	similar, although raw data suggest increased abundance, in survey within 12/24 months of construction

Structure	*Reference*	*Habitat*	*Structure details*	*Methodology*	*Survey design*	*Benthic species effect*	*Fish effect*	*Commercial species effect*	*Fishing catches effect*	*Similarity to natural habitat*
Wave power devices	Langhamer et al (2009)	soft sand/silt gravel, 25m deep, 2km offshore	5 concrete wave power 3 with holes	Visual census PRIMER	Temporal, Spatial	Increase Ascidiaceae *P. triqueter* *Balanus sp.* *M.edulis*	Increase	yes, *Cancer pagurus* *Gadus morhua*	not studied	not studied, observed different to surroundings
Wave power devices	Langhamer and Wilhelmsson (2009)	flat sand /silt gravel, 2km offshore, 25 m deep	5 wave power devices constructed 2005. 21 concrete bases added 2007. 11 with holes	Visual census, footing and 8m surround as control, Wilcoxon, Mann-Whitney U test.	Spatial	not studied	Increase	yes, increase *G.morhua* (only 2 individuals) *C.pagarus* all associated with shelter	not studied	dissimilar, greater abundance of crustaceans
Artificial reef	Sayer et al (2005)	13-19 m deep	concrete block reefs with and without holes, 40 m diameter 3.5m high	Visual census ECOSIM Model	Temporal	not studied	Increase	Increase	Increase, Positive if design is to provide species specific responses	suggested similar for fish
Artificial ree	Jenson et al (1994)	flat sand, 10m deep, 3 km to natural reef	8 reefs, gypsum, coal ash block 300m²	Visual census, Baited pots, Nets, Core sampling, Cluster analysis, ANOVA, Shannon-Wiener,	Temporal, Spatial	Increase *P. triqueter* *Balanus sp.* *Scypha ciliata*	Increase *Trisopterus lucus*, *Labridae spp.* *Mullus surmuletus*	yes *T. lucus* *C.pagurus* *H.gammarus* *Sepia officinalis*	not studied	dissimilar with similarity over time

Structure	*Reference*	*Habitat*	*Structure details*	*Methodology*	*Survey design*	*Benthic species effect*	*Fish effect*	*Commercial species effect*	*Fishing catches effect*	*Similarity to natural habitat*
Artificial reef	Hunter and Sayer (2009)	10-20m deep, Sand/mud	30 reef modules Complex and non complex 3.5m high 40m diameter	Visual census, belt transect, ANOVA, Shannon-Wiener,	Temporal, Spatial	Increase complex reef *C.melops, C.exoletus, Necora puber, C. pagarus*	Increase complex reef *C.melops C.exoletus*	Increase – complex *C.pagurus*	not studied but commercial species increase in abundance	dissimilar – natural more variable inter season, complex and natural most. similar overall
Oil Rig	Soldal et al (2002)	offshore, pelagic, north sea, 70 m deep, sand and clay	oil rig 50 x 65m	hydro acoustic survey, under water video, survey trawls, GLM analysis,	Spatial, Temporal	not studied	Increase in immediate area only	Increase *G.morhua P.virens Molva molva*	not studied but commercial species increase in abundance	aggregation possible
Oil Rig	Lokkeborg et al (2002	offshore, pelagic, north sea, 70 m deep, sand and clay	oil rig 50 x 65m	experimental gill net ANOVA	Spatial, Temporal	not studied	Increase, with change in distribution with season	Increase *G.morhua Molva molva P.virens*	not studied but commercial species increase in abundance	pelagic aggregation

Structure	*Reference*	*Habitat*	*Structure details*	*Methodology*	*Survey design*	*Benthic species effect*	*Fish effect*	*Commercial species effect*	*Fishing catches effect*	*Similarity to natural habitat*
Oil Rig	Jorgensen (2002)	offshore, pelagic, north sea, 70 m deep, sand mud and gravel	oil rig 50 x 65m	tag and release VEMCO pinger tags	Temporal Spatial	not studied	Increase 18/29 cod remain after 3 months, 4/29 after one year	Increase *G.morhua*	not studied but commercial species increase in abundance	pelagic aggregation. also show behavioural difference between individuals and movement between platforms.
Gas Platform	Love et al (1994)	Pacific Ocean, 123m deep	Gas platform, 60m diameter mussel mounds 6-8 m high	ROV photographic cluster analysis tag and releas isual scuba ANOVA	Temporal, spatial	not studied	Increase change with season – juveniles leave	Increase	not studied but commercial species increase in abundance	juvenile habitat? Increased abundance at platform compared to natural.
Gas Platform	Love et al (1999)	Pacific Ocean, 123m deep mussel mounds	Offshore rigs 60 m diameter, mussel mound 6-8m high	visual / video cluster analysis / video	Spatial	not studied	Increase	Increase *Sebastes spp*	not studied but commercial species increase in abundance	Solitary benthic species at mounds, less abundance /density than platform bottoms. Assemblages on mounds similar to adjacent platform not natural reefs. Often smaller individuals.
Shipwreck (steel)	Hiscock et al (2010)	20 m deep Sand	Steel ship wreck With anti foul paint	Visual survey suction sampler	Temporal, spatial	Increase but lacks Rare species	Increase *P.pollachius* *T.luscus* *T.minutus*	Increase *P.pollachius*	not studied	dissimilar with concern of alien species colonising an area

Structure	*Reference*	*Habitat*	*Structure details*	*Methodology*	*Survey design*	*Benthic species effect*	*Fish effect*	*Commercial species effect*	*Fishing catches effect*	*Similarity to natural habitat*
Sea Wall, harbour	Blockley (2007)	Shoreline Sea wall	Seawall 7 locations Within bays and inlet Shaded portion	Visual survey 5m² of the habitat surveyed, PERMANOVA	Spatial	Increase	not studied	not studied	not studied	dissimilar large spatial variability amongst seawalls
Marinas	Clynick et al (2006)	Shoreline Bays, risa, inlets <15m deep	Marinas Swimming enclosure Natural reefs At 5 locations	Visual survey belt transect 20m x 4m ANOVA ray – Curtis	Spatial	not studied	Increase with similarity to natural	not studied	not studied	variable similarity, with spatial differences and species specific differences

Appendix 2. *Interview script and mapping components used for resource user interviews.*

Introduction

This survey is to understand how fishing activities have changed over the last ten years with the development of renewable energy sites amidst a number of pressures on the fishing industry. The survey aims to record the experiences of daily activity of fishermen in this time and individuals thoughts on these effects. The information provided in this questionnaire will be anonymous and aims to examine changes at the level of vessel size and gear type not activities of individual vessels. The results of analysis of all surveys will be presented and discussed in a university thesis and potential scientific publications in fisheries and social science areas.

By completing this questionnaire your information will be used anonymously and only be displayed aggregated with all other information from people using similar gear types and fishing in this region. If you are not comfortable giving certain information you are under no obligation to do so and have the right to withdraw information at a later date by contacting myself or the university.

Fishermans background

Years Fishing:	
Years as skipper:	
Age:	18-30 31-40 41-50 51-60 60
Fishing full time (100%) or other work too?	

Vessels details

Current home port:	
LOA:	
Engine KW:	
Number of other crew:	
Which port do you usually land your catch:	
Length of average trip (days/hours)	

% of total annual effort occurring within Greater Thames / Liverpool Bay/ Greater Wash area (present day)	

Why do you fish the current grounds you visit and use the gears you do? (record)

Ground	**summer**	**autumn**	**winter**	**spring**

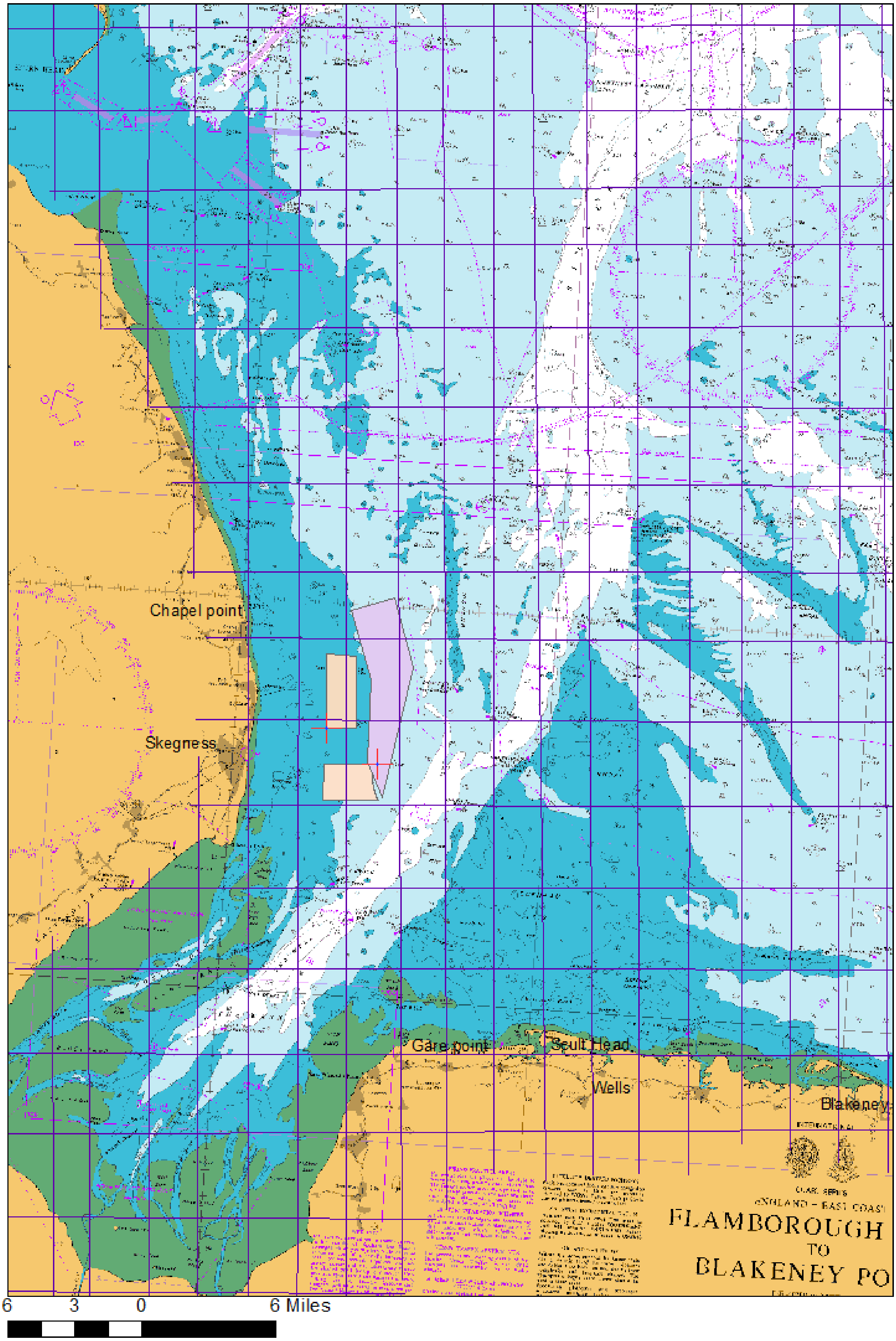
Quarterly activity – please record your typical quarterly activity from recent seasons in the table below using the following gear key: *Static* *Gill net -**1**, Tangle net -**2** Trammel net -**3** pots -**4** Traps* **5 *Mobile*** *Beam trawl -**6** Otter trawl -**7** Scallop dredge -**8** Mid-water trawl -**9** Long lines -**10** Ring net -**11** Handlines -**12***

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="5">Gear type (please use code at top of table)</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Quarter 1 (Jan –Mar)</td><td>Effort</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Target species</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Quarter 2 (Apr-Jun)</td><td>Effort</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Target species</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Quarter 3 (Jul-Sep)</td><td>Effort</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Target species</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Quarter 4 (Oct-Dec)</td><td>Effort</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Target species</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">% of total annual earnings</td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Where do you currently fish?

If you do not want to supply specific marks please locate a general area in reference to mapped landmarks. Map provided below (for phone interviews please describe in reference to locations e.g. 1 mile north east of windfarm).

Please indicate your principle fishing areas for each quarter on the map below by writing Q1, Q2, Q3, Q4 and gear used (following the key used earlier 1- *Tangle net*, **2, 3) in corresponding grids.**


Chapel point
Skegness
Gare point
Scult Head
Wells
Blakeney
FLAMBOROUGH
TO
BLAKENEY PO
6
3
0
6 Miles

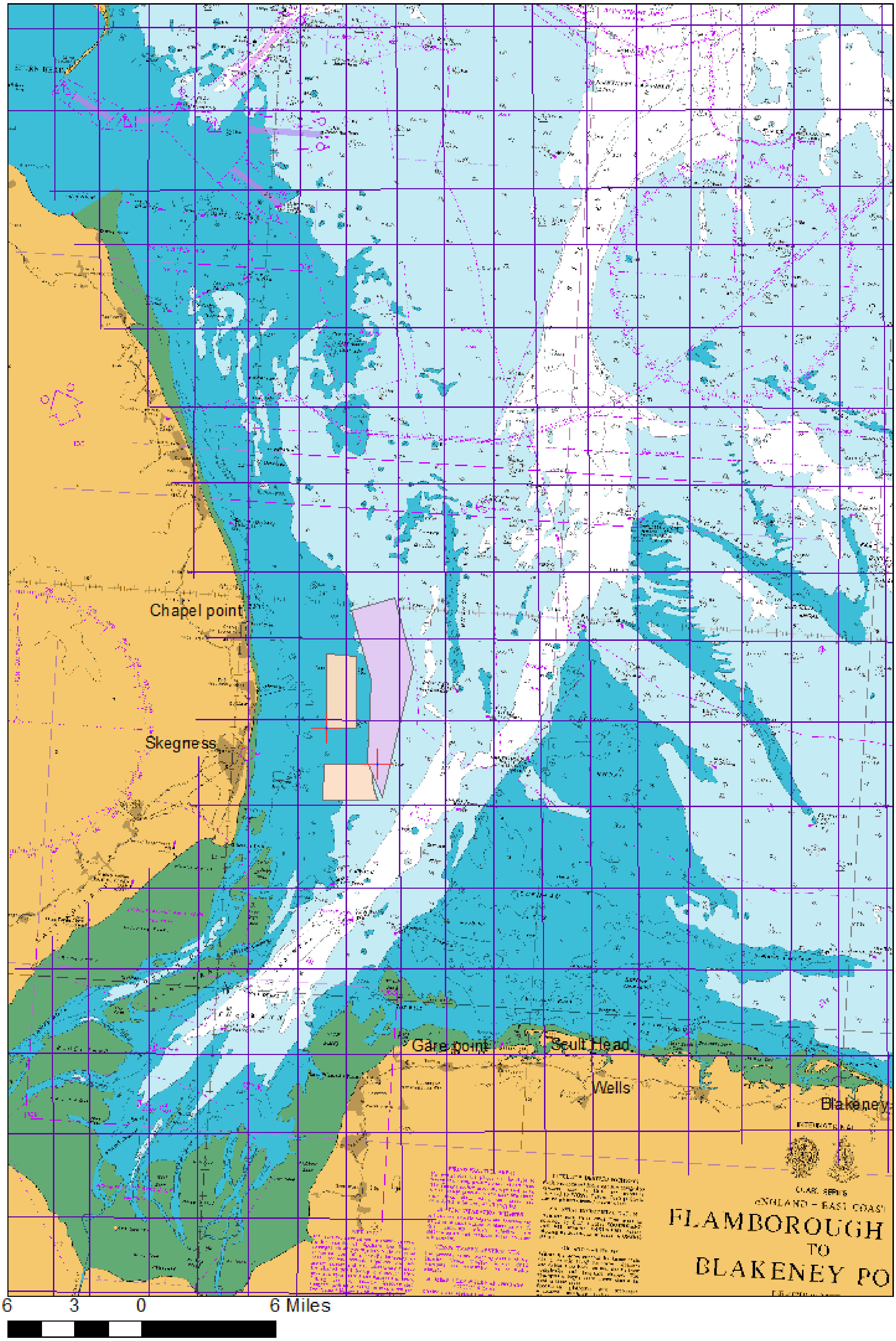
Has your fishing activity changed in the past ten years?

Section1: **Quarterly activity – Please give details of the areas of activity (gear, target species and season) that were different 5-10 years ago :** ***Static*** *Gill net -**1**, Tangle net -**2** Trammel net -**3** pots -**4** Traps **5*** ***Mobile*** *Beam trawl -**6** Otter trawl -**7** Scallop dredge -**8** Mid-water trawl -**9** Long lines -**10** Ring net -**11** Handlines -**12***

Same but now less and areas species found has changed. Missing tub gurnards, now seem to find species have moved offshore and inshore a lot more.		Gear type (please use code at top of table)				
Quarter 1 (Jan –Mar)	Effort					
	Target species					
Quarter 2 (Apr-Jun)	Effort					
	Target species					
Quarter 3 (Jul-Sep)	Effort					
	Target species					
Quarter 4 (Oct-Dec)	Effort					
	Target species					
% of total annual earnings						

% of total annual effort occurring within Greater Thames / Liverpool Bay/ Greater Wash area (present day)	

If your fishing activity has changed over the last 10 years where did you fish 10 years ago?



Chapel point
Skegness
Gare point
Scult Head
Wells
Blakeney
ENGLAND - EAST COAST
FLAMBOROUGH
TO
BLAKENEY PO
6
3
0
6 Miles

Catches

Have your catches changed in the last 10 years?

Why do you think this is?

Have changes occurred for specific species?

Species	% Increase or decrease?	Year or years this occurred. If all years since construction please just put 'all'	Reason

If possible do you have records of catches I can see to help record this?

SECTION B – YOUR VIEWS.

To what extent do you agree to the following statement?

I have changed my fishing activities because of the windfarm	Strongly disagree	disagree	not sure	agree	Strongly agree
	1	2	3	4	5

In your view how may the windfarm have influenced your fishing activity? *Record and code*

Are there other factors that have influenced your activity and catches? *Record and code*

Of the factors mentioned which do you consider to have the greatest influence on you activity and which have the least influence? Please rank them with the greatest influence first.

To what extent do you agree with the following statement?

My catches have changed due to influence of the windfarm	Strongly disagree	disagree	unsure	agree	Strongly agree
	1	2	3	4	5

In your view how and why may the windfarm have influenced your catches? *Record and code*

What other factors do you think have led to changes in catches over the past five to eight years? *Record and code*

What specific effects have you noticed to daily activity, income and catches that may relate to the windfarm site? *(table below + record and ask why do you think this is and code answers)*

Effects	
Abundance of specific species close to the site (fish/crabs/lobster/whelks etc)	Increase/decrease/no change
Distance travelled to grounds	Increase/decrease/no change
catch of principal target species	Increase/decrease/no change
Time spent fishing per trip	Increase/decrease/no change
Effort in remaining available grounds	Increase/decrease/no change
Income from other sources using the boat such as windfarm supply	Increase/decrease/no change
Income from fishing	Increase/decrease/no change
Gear and vessel purchase and maintenance costs	Increase/decrease/no change
Other: please provide details and increase, decrease, stay the same	Increase/decrease/no change

Which fishing activity options are you likely to consider in the next 2-5 years?

	Yes	No	Maybe
Continue fishing remaining ground using same methods			
Change gears and continue in existing ground			
Search for new grounds and use existing gears			
Search for new grounds and change gears			
Stop fishing			
Other – please specify			

Why are you considering these options? *Record and code*

What in your view is the best planning scenario for this region to accommodate fishing, renewable energy arrays and marine conservation zones?

Thankyou for taking the time to share your views and experience but importantly is there any information or topics that have been missed by this survey that you would like to share, especially advantages or disadvantages you have experienced?

Appendix 3

West of Walney proposed Marine Conservation Zone (partial OWF and MPA co location zone) (Defra 2012, 2012b).

Location:

Irish Sea:

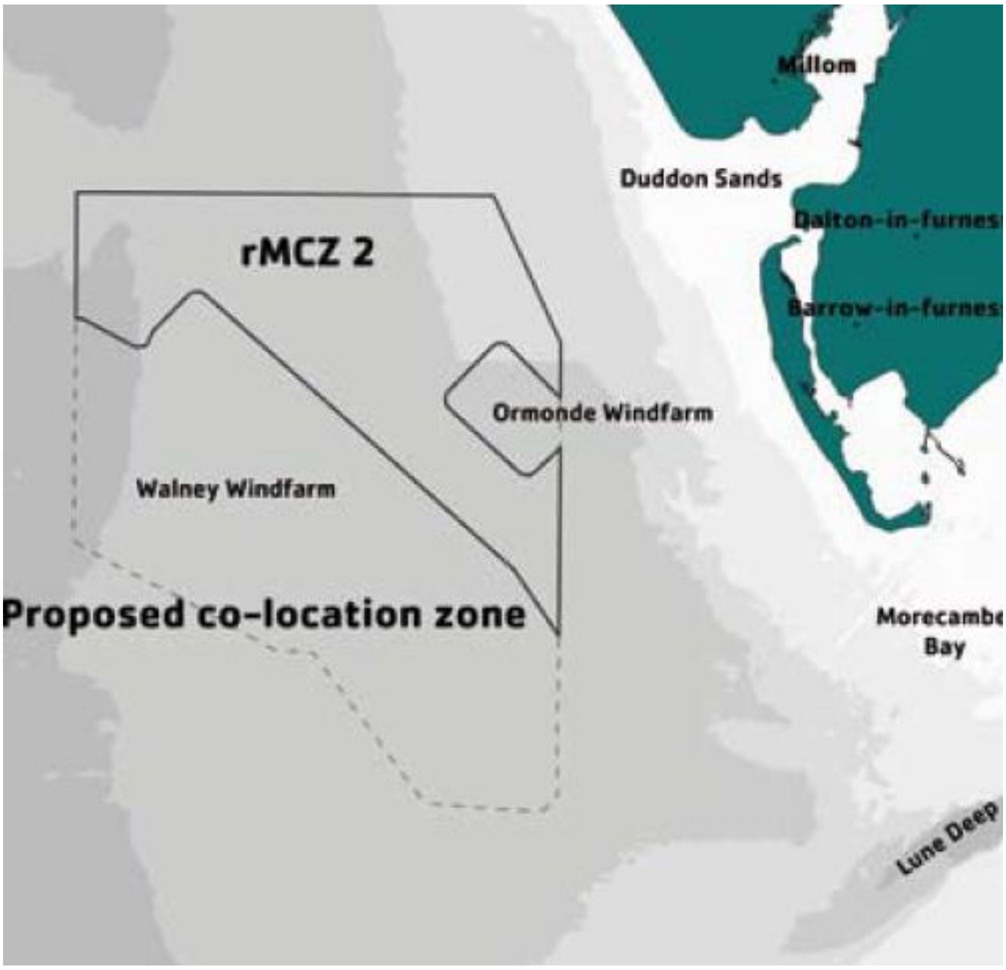


Figure 7.1 Map of the Walney pMCZ and pCLZ off the coast of North West England in the Eastern Irish Sea. (Image reproduced from the Wildlife Trusts 2013)

Description:

Habitat: Subtidal sand is the broad scale habitat of conservation importance in the co-location zone. Subtidal mud, mud habitats in deep water, sea pen and burrowing mega fauna communities are considered of importance in the wider proposed marine conservation zone.

Objective:

Recover: The objective for the MCZ, including the colocation zone is to recover habitats

Management scenarios:

Management scenario 1: Entire PCLZ is open to all gear types.

Management scenario 2: Closure of entire PCLZ to bottom trawls (excluding seine nets) and dredges.

Management scenario 3: Closure of entire PCLZ to bottom trawls and dredges.

Economic impacts:

Fishing industry

Annual economic impacts were calculated for the PCLZ as part of the social and economic impact assessment by Irish Sea Marine Conservation Zone Project. Annual economic impacts were calculated for the commercial fishing industry as, £0 if the windfarm and marine conservation zone remained open to fishing (management scenario 1) or £968000 under management scenarios 2 and 3.

Renewable energy industry

Annual economic impact values for the renewable energy industry were calculated as £4000 under scenario 1. Under management scenarios 2 and 3 a one off cost of £ 12480000 (additional sheathing and cable routing) and additional consultancy and monitoring costs of £546000 is calculated (Defra 2012, 2012b). The renewable energy industry developers concerned with Walney OWF suggested that there may be costs of up to £176 million over the 20 year lifespan of the OWF. JNCC and Natural England state there is a low likelihood of these additional requirements and associated costs to the renewable energy industry being required.

Proposed benefits

The objective of the PCLZ is to recover the subtidal sand bank habitat within the PCLZ. This is also the objective of the surrounding pMCZ with the additional objectives or recovering mud habitats in deep water, sea pen and burrowing mega fauna communities. The cessation of bottom trawling and dredging in management scenarios 2 and 3 could provide opportunity for benthic species richness to increase. Benefits are identified for the recovery of brittle stars and sea pens which are sensitive to bottom trawling impact (Greathead et al. 2007, Kaiser et al. 2000 in Blythe et al. 2002). Increase in fish and crustacean biomass is identified as a possibility which if spill-over of these resources occurs will generate benefits for vessels fishing just outside the pCLZ and neighbouring MCZ (Blythe et al. 2002, Reid 2011, Bennett and Hough 2007, Sweeting and Polunin, 2005). The reduction in bottom trawl and dredging fishing practices is also identified to benefit static gear fishermen (reducing conflict and increasing grounds available).

Current situation

There is limited data certainty for the site with further work prior to designation identified. Further work is required to ensure advantages from protection are sufficient to justify the socio-economic implications. There are high costs to the renewable energy industry in particular for construction and monitoring practices to fulfil heightened consenting requirements.

Implications of the findings of thesis and related literature

Subtidal sand is the habitat feature of interest in the co-location zone. The potential modification of this habitat type from presence of OWF structures will be important to consider. The change in sediment identified at North Hoyle with the increase of coarser sediment in proximity to turbines and the scouring likely to be present is important to understand in respect to the habitat within the MCZ.

The reduction in towed fishing gear activity is likely to benefit the organisms (sea pens and brittle stars) within the MCZ as predicted. The balance between these benefits and the ability for a rich biologically diverse community to develop will be important to monitor under the ‘recover’ objective if sediment characteristics change rapidly.

Brittle stars, identified as a target species for recovery will benefit if trends occur as in North Hoyle (also in the Eastern Irish Sea).

The predicted fish and crustacean biomass increase is supported by results at North Hoyle and particularly monitoring of similar OWFs in Sweden and Belgium. In these examples from European seas catches and occurrence of commercial species were greater at closer distances to turbines (Bergstrom et al. 2012; Reubens et al. 2013).

Spill over of fish and crustacean populations and the benefit of production over merely attraction are yet to be shown. The high abundance of juveniles of commercially targeted species identified at North Hoyle and other European OWFs is likely to benefit wider populations. The fitness of fish occurring in a Belgium OWF was shown to be equal to individual fish occurring on natural habitats (Reubens et al. 2013). In addition to the abundant food resources available there is, therefore, good evidence for benefits of OWF habitats for juvenile gadoid fishes. This may benefit the sustainability of fisheries on a regional basis while there are benefits from increased abundance of crustaceans for static fisheries. These benefits would be maximised if appropriate scour protection and armouring are utilised. The region has historically provided fishing opportunities for flatfish species and it will be important to monitor effects on this fishery.

Appendix 4

North of Lundy proposed Marine Conservation Zone (partial OWF and MPA co-location zone) (Defra 2012a, 2012b).

Location:

Bristol Channel:

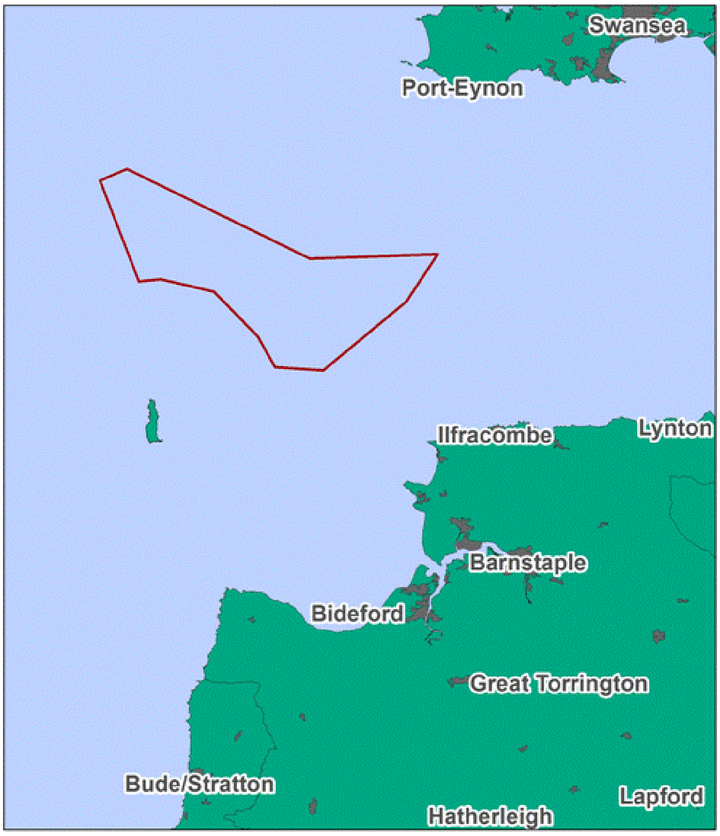


Figure 7.2 Map of the North of Lundy pMCZ and pCLZ off the coast South West England in the Bristol Channel.(Image reproduced from the Wildlife Trusts 2013)

Description:

Habitat: Moderate energy circalittoral rock, subtidal coarse sediment, subtidal mixed sediment, subtidal sand

Objective:

Maintain at favourable condition

Management scenarios:

Management scenario 1: No additional management.

Management scenario 2: Zoned closure of areas of moderate-energy circalittoral rock in the rMCZ to bottom trawls and dredges.

Management scenario 3: Closure of entire rMCZ to bottom trawls and dredges.

Economic impacts:

Fishing industry

Annual economic impacts on the fishing industry were calculated from landings and activity patterns available from VMS and aerial surveillance data.Values are for the whole rMCZ including the Atlantic Array OWF. Under scenario 1economic impact was indicated to be £0 to £1000. Under scenario 2, £19000 and under scenario 3, £ 138888 commercial fishing,

The regional fishermen's associations have expressed concern that under scenario 3 the economic impact of the OWF alone would be £2 000 000 per annum based on current fishing activity and there would be knock on effects on hundreds of jobs (North Devon Fishermen's Association in Defra 2012a).

Renewable energy industry

Under management scenarios 1, 2 ad 3 the economic cost to the renewable energy developer for Atlantic Array OWF are calculated as £6000.

The renewable energy developer has expressed concern that over the 20 year lifespan of the OWF additional monitoring costs could be £177 000 000 (Defra 2012a, 2012b)

JNCC and Natural England state there is a low likelihood of these additional requirements and associated costs to the renewable energy industry being required.

Proposed benefits

The North of Lundy MCZ contains sand and gravel sediments as well as boulder and rock substratum. The region supports higher than average benthic species diversity and supports important foraging areas for sea birds. These species are noted by Finding Sanctuary and Natural England, JNCC, DEFRA to contribute to the delivery of a range of ecosystem services.

Reduction in fishing effort within the MCZ, including the co-location zone is suggested to possibly benefit commercial stocks. Reduction in fishing effort could be considerable as effort is presently relatively high. Economic benefits are raised as being possible for fishermen utilising fishing practices permitted within the MCZ and co-location zone. The potential benefits of spill over of stocks to areas being fished by all fishermen are also raised.

Current situation

Confidence in the certainty of the outcomes is currently low.

Implications of the findings of thesis and related literature

The North of Lundy pMCZ and co-location zone contains soft sediment as well as boulder and rock sub stratum. The maintenance of rock and boulder habitats and the associated higher than average biodiversity may be aided by the presence of the Atlantic Array OWF and additional hard substratum provided. The reduction of fishing effort within the array, particularly the use of towed gears will potentially aid the recovery of epifauna communities (Kaiser et al. 2006). Again it is important to consider the effect of changes in sediment characteristics from scouring and construction activities on the benthic community assemblages and associated fish communities.

A diverse range of fisheries operate in the region, the local fleet consist of vessels using traps for lobster and whelk, and mobile trawling activity for mixed demersal fishing. A smaller number of vessels also operate nets, principally for bass. Recognised lobster and whelk fishing grounds are present in the OWF which may potentially be aided by the additional habitat and communities colonising the new turbine structures. If mobile fishing activity is reduced in the OWF and static fisheries maintain access there is reduced potential for conflict (where pots and nets may be caught in trawls). Catches for static fisheries may increase through potential for target species abundance to increase in relation to the OWF habitat. If all fisheries are displaced conflict is likely to increase as all fisheries compete on reduced available grounds. Increased fishing activity in remaining grounds may also have negative effects on existing species diversity in these unprotected areas.

The ecological, economic and social costs of changes in spatial fishing activity appear not to have been accounted for. This site provides a diverse mix of habitats, species diversity and economic activity in a restricted area. It would appear particularly important at this site to monitor species abundance and diversity inside and outside the pMCZ. The effects of displaced fishing activity, extent of spill over benefits and the economic and social implications for fishing and other marine activities may impact the conservation objectives within the wider area.

Appendix 5

Inner Dowsing, Race Bank and North Ridge candidate Special Area of Conservation (cSAC) (JNCC 2010),

Location:

North Sea:

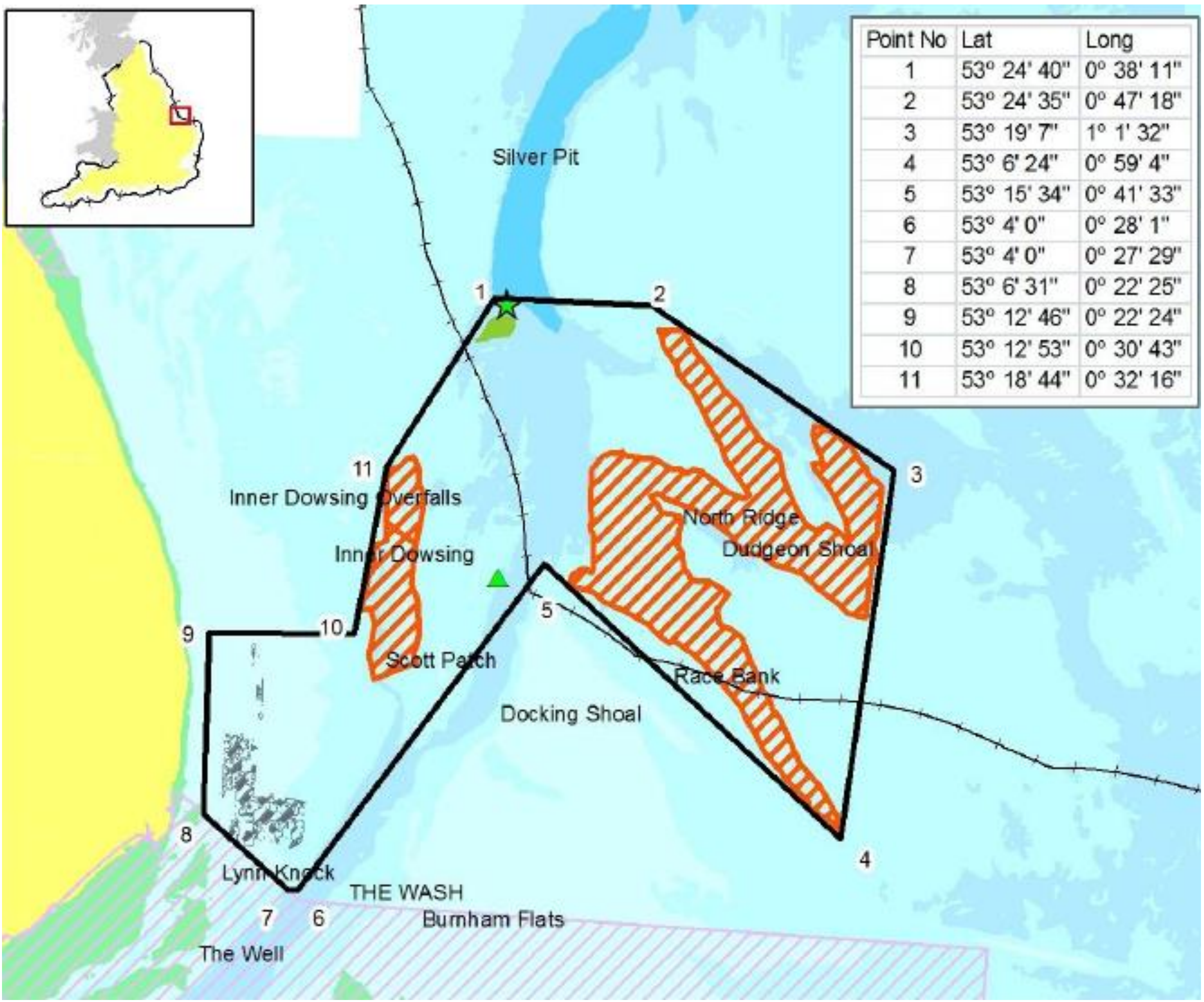


Figure 7.3 The Inner Dowsing, Race Bank and North Ridge candidate Special Area of Conservation off the Coast of Lincolnshire in the Greater Wash (Reproduced from JNCC 2010).

Description:

Habitat: The Inner Dowsing, Race Bank and North Ridge candidate Special Area of Conservation contains two important habitat types; Sandbanks that are slightly covered by sea water all the time and reefs.

Infrastructure: The site incorporates existing offshore wind farms (Lynn and Inner Dowsing), one wind farm under construction (Lincs) and one further wind farm has been consented within the cSAC boundary (Race Bank) (Figure 5.2).

Objective:

This cSAC aims to allow the sandbank and reef habitats to achieve their full natural biological diversity, and maintained or restore the underlying physical structure. Specific conservation objectives to maintain the sandbank habitats in favourable condition are stated as:

- *Maintain the extent, physical structure, diversity, community structure and typical species representative of low diversity dynamic sand communities and moderate diversity stable sand communities (or restore where deterioration has occurred).*

Management scenarios:

The competent authorities responsible for management of human activities within their remit are advised to ensure activities do not result in deterioration or disturbance; or impede the restoration of this feature through any of the following:

i) **Physical loss** by Removal (e.g. aggregate dredging, demersal trawling, benthic dredging) or Obstruction (e.g. oil and gas industry and renewables infrastructure);
ii) **Physical damage** by Physical disturbance or abrasion (e.g. demersal trawling, benthic dredging), Changes in suspended sediment (e.g. aggregate dredging, demersal trawling, benthic dredging, renewables infrastructure);
iii) **Toxic contamination** by introduction of Synthetic and/or Non-synthetic compounds (e.g. pollution from oil and gas industry, shipping);
iv) **Non-toxic contamination** by Changes in turbidity (e.g. aggregate dredging, demersal trawling, benthic dredging; installation renewables infrastructure);
v) **Biological disturbance** by Selective extraction of species (e.g. demersal trawling, benthic dredging).

Economic impacts:

Socio-economic factors are not taken into account in the identification of SACs to be proposed to the European Commission. Sites eligible for designation as Special Areas of Conservation (SACs) are selected on the basis of the criteria set out in Annex III (Stage 1) to the Habitats Directive and relevant scientific information. SACs are considered only if they host a Habitats Directive Annex I habitat or Annex II species.

Potential benefits

Recovering and maintaining the Annex I habitats in the region will preserve important regional sandbank and reef habitat and contribute to a wider network of ecologically coherent marine protected areas (MPAs). The silty sand and gravel deposits within the cSAC support a diverse communities characterised by a range of species. Habitat characterised as Annex 1 reef contains the reef building Ross worm *S.spinulosa.*

The cSAC contains important habitat for commercially targeted fish species. Spawning grounds for herring (*Clupea harengus)*, lemon sole (*Microstomus kitt)* and sole (*Solea solea)* are contained within the cSAC (Coull et al. 1998; Ellis et al. 2012). The cSAC also contains nursery areas for cod (*Gadus morhua)*, herring, sole, lemon sole and plaice (*Pleuronectes platessa*) (Coull et al. 2001). Cod, sole and thornback ray (*Raja clavata*) are the dominant commercial species occurring within the cSAC.

Recovery and maintenance of the Annex I habitats could ensure populations and stocks of commercially important species remain at sustainable levels, benefitting fisheries in the region in the long term.

Current situation

JNCC have established draft Conservation Objectives for the cSAC and have advised Competent Authorities on appropriate management actions.

Marine Management Organisation(MMO) have completed draft marine plan for the management of activities in relation to this and other marine protected areas in the region. The draft marine plans are currently in the public consultation phase (MMO 2013b).

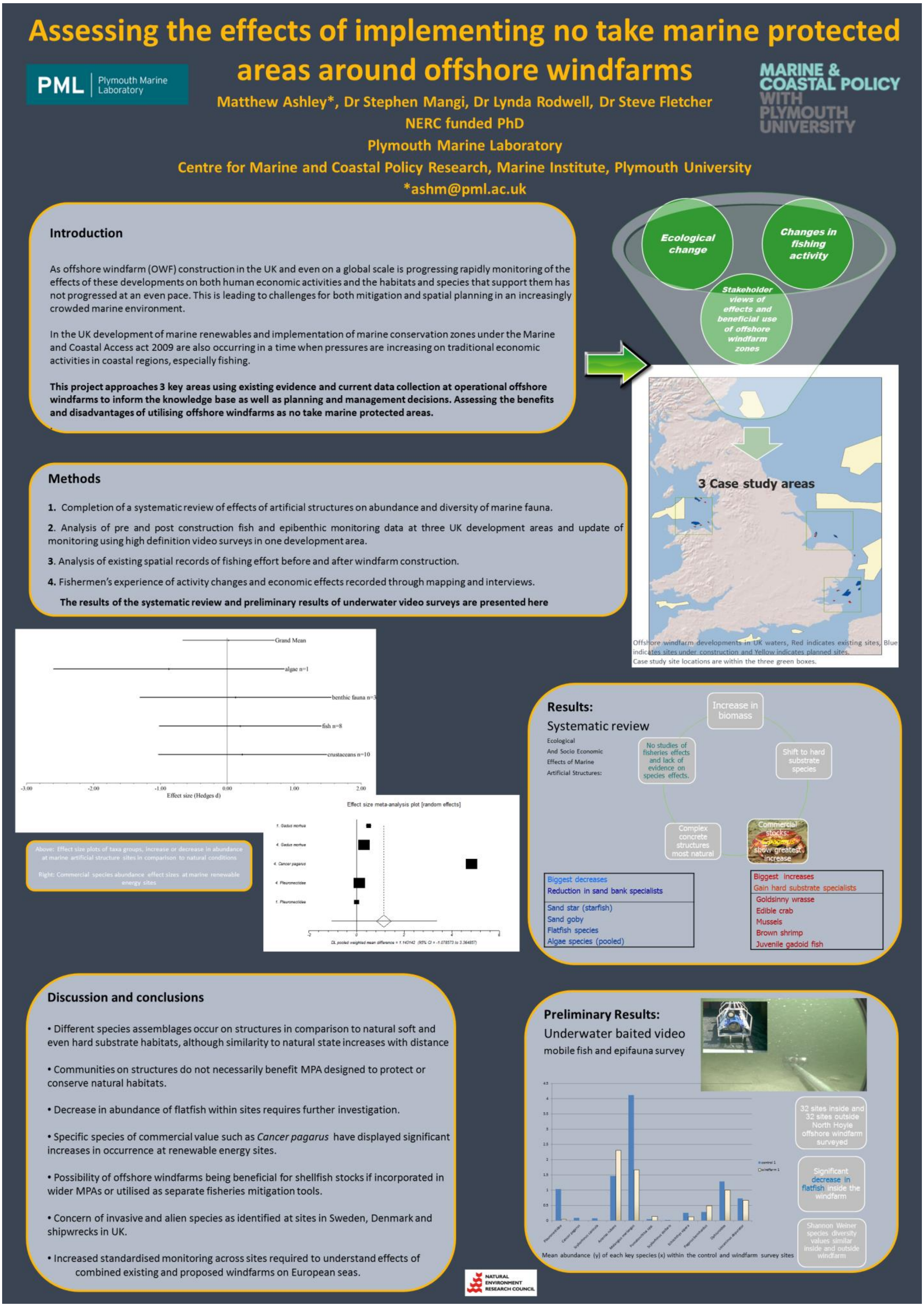
The European Commission is yet to approve the Inner Dowsing, Race Bank and North Ridge cSAC.

Implications of the findings of thesis and related literature

In relation to thesis results construction activity and changing sediment characteristics as a result of scouring are likely to influence the existing 'extent, physical structure, diversity, community structure and typical species representative of low and moderate diversity stable sand communities.' Use of scour protection methods to address changes in physical structure and subsequent changes in naturally occurring communities would appear important to managing 'physical loss, physical damage and biological disturbance.' Monitoring of physical disturbance and biological community change against a detailed baseline data set would be important for assessing impacts and recovery.

Effects of OWF construction and operational activity on spawning grounds for herring, lemon sole, sole and plaice will also be important to monitor and mitigate. Both the findings from this thesis on changes in flatfish abundance and the reduction in herring spawning stock displayed at Scroby Sands OWF suggest these species may receive limited benefits from OWF construction (Perrow et al. 2011). As a nursery area for cod the presence of OWFs in proximity to the pSAC is likely to provide habitat and food resources to aid this species.

Appendix 6. *Poster presented at the 1st Marine and Coastal Policy Forum, June 2011 and also the 4th Annual Plymouth Marine Science Education Fund Conference, Blue Horizons, Plymouth December 2011.*



Peer reviewed papers from thesis chapters:

Ashley M. C., Mangi S. C., Rodwell L. D., 2013. The potential of offshore wind farms to act as marine protected areas – a systematic review of current evidence. Marine Policy 45: 301-309